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Health Technical Memorandum 2025

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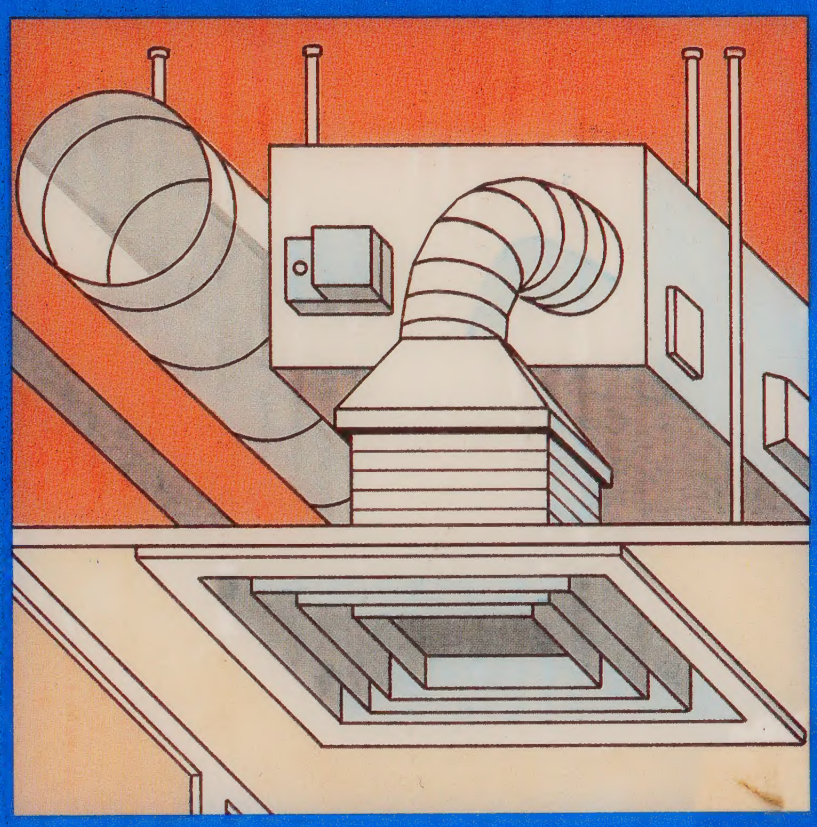
Design considerations

Ventilation in healthcare premises



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Health Technical Memorandum 2025

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Ventilation in healthcare premises

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About this publication

Health Technical Memorandum (HTM) 2025 gives comprehensive advice and guidance on the operation of ventilation in all types of healthcare premises.

It is applicable to new and existing sites, and is for use at various stages during the inception, design, upgrading, refurbishment, extension and maintenance of a building.

HTM 2025 focuses on the:

a. legal and mandatory requirements;

b. design of systems;

c. maintenance of systems;

d. operation of systems.

It is published as four separate volumes, each addressing a specialist discipline:

a. **Management policy** – considers the overall responsibility of managers of healthcare premises. It outlines legal obligations and clinical needs with respect to ventilation, summarises the technical aspects and concludes with guidance on the management of systems;

b. this volume – **Design considerations** – does not set out to give detailed instruction in design but highlights the overall requirements and considerations that should be applied to the design up to the contract documentation;

c. **Validation and verification** – gives general advice for ensuring that the installed equipment has been formally tested and certified as to contract. The importance of correctly setting to work and commissioning the completed installation is emphasised. The handover procedure, including the provision of documentation and training, is set out;

d. **Operational management** – provides information to those responsible for overseeing day-to-day operation and maintenance. Safe systems of work, record-keeping and legal obligations are included.

Guidance in this Health Technical Memorandum is complemented by the library of National Health Service Model

Engineering Specifications. Users of the guidance are advised to refer to the relevant specifications.

The contents of this Health Technical Memorandum in terms of management policy, operational policy and technical guidance are endorsed by:

a. the Welsh Office for the NHS in Wales;

b. the Health and Personal Social Services Management Executive in Northern Ireland;

c. the National Health Service in Scotland Management Executive;

and they set standards consistent with Departmental Cost Allowances.

This HTM was written with the advice and assistance of experts in the NHS and industry.

References to legislation appearing in the main text of this guidance apply in England and Wales. Where references differ for Scotland and/or Northern Ireland these are given in marginal notes.

Where appropriate, marginal notes are also used to amplify the text.

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1.0 Introduction

General

1.1 Ventilation is used extensively in healthcare premises for primary patient treatment in operating departments, intensive treatment units and isolation suites. It is also installed to ensure compliance with quality assurance of manufactured items in pharmacy and sterile supply departments and to protect staff from harmful organisms and toxic substances, for example in laboratories.

1.2 This edition of Health Technical Memorandum 2025 Ventilation in healthcare premises is published in separate sections. It is equally applicable to both new and existing sites. It gives comprehensive advice and guidance to healthcare management, design engineers, estates managers and operations managers on the legal requirements, design implications, maintenance and operation of specialist ventilation in all types of healthcare premises.

1.3 Current statutory legislation requires both "management" and "staff" to be aware of their collective responsibility.

1.4 "Ventilation" is provided in healthcare premises for the comfort of the occupants of buildings. More specialised ventilation will also provide comfort but its prime function will be to closely control the environment and air movement of the space that it serves in order to contain, control and reduce hazards to patients and staff from airborne contaminants.

1.5 Ventilation systems in themselves present little danger to patients or staff; however, they do possess the ability to transmit hazards arising from other sources to large numbers of people. The danger may not become apparent until many patients and staff have been affected.

1.6 The sophistication of ventilation systems in healthcare premises is increasing. Patients and staff have a right to expect that it will be designed, installed, operated and maintained to standards that will enable it to fulfil its desired functions reliably and safely.

Definitions

1.7

Air distribution – the transportation of air to or from the treated space or spaces, generally by means of ducts.

Air diffusion – distribution of the air in a treated space, by means of air terminal devices, in a manner so as to meet certain specified conditions, such as air change rate, pressure, cleanliness, temperature humidity, air velocity and noise level.

Supply air – the air flow entering the treated space.

Exhaust air – the air flow leaving the treated space.

Exhaust may be implemented by one or more of the following methods:

a. extraction: exhaust in such a manner that the air is discharged into the atmosphere;

b. relief: exhaust in such a manner that the air is allowed to escape from the treated space if the pressure in that space rises above a specified level;

c. re-circulation: exhaust in which the air is returned to the air treatment system;

d. transfer: exhaust in which air passes from the treated space to another treated space.

Dampers – components inserted into air ducts, or used in conjunction with air terminal devices, which when activated permit modification of the air resistance of the system and consequently a change; complete shut-off; or control of the air flow rate.

Dampers can be:

a. multiple-leaf – comprising a number of opposed or parallel blades;

b. single-leaf dampers – commonly called splitter dampers, having two or more slotted slides;

c. butterfly dampers – with two flaps in a "V" arrangement;

d. iris dampers – with inter-leaving vanes.

Fire dampers – components which are installed in an air distribution system between two fire separating compartments and are designed to prevent propagation of fire and/or smoke.

They are maintained open until activated by fire or smoke detection.

Sound attenuators/silencers – components which are inserted into the air distribution system and designed to reduce noise being propagated along the ducts.

Air terminal device – a device located in an opening provided at the end of the duct to ensure a predetermined motion of air in the occupied space.

Supply air diffuser – a supply air terminal device through which air enters a treated space.

It usually consists of one or more deflecting blades, which produce a reduction of the air velocity to a suitable level in the occupied zone; a given direction of throw; and efficient mixing of the supply air with the air in the treated space. May be of the fixed, or adjustable type.

Exhaust grille – an air terminal device with multiple passages for the air, through which air leaves the treated space. May be of the fixed, or adjustable type.

Slot diffuser – a diffuser with one or several slots with an aspect ratio of 10:1 or more for each slot.

Register – a combined grille and damper assembly.

Nozzle – an air terminal device designed to generate a low energy loss and thus produce a maximum throw by minimum entrainment.

Nominal Size – of an air terminal device is the nominal value of the dimensions of the opening required to mount the air terminal device in.

Effective area – of an air terminal device is the smallest net area used by the air stream in passing through the air terminal device.

Envelope – the geometrical surface of the points of an air jet.

Throw – for a supply air terminal device, is the maximum distance between the centre of the core and the extremity of the terminal velocity envelope.

Induction – process by which the primary air entrains secondary air into motion in the room.

Induction ratio – ratio of the combined primary and secondary air flow rate to the primary air flow rate.

Spread – for a supply air terminal device, is the maximum width of the terminal velocity envelope.

Drop – for a supply air terminal device, is the vertical distance between the extremity of the terminal velocity envelope and the air terminal location plane.

Coanda effect – also called ceiling or wall effect, is the tendency of an air stream to follow a plane when the stream is in contact with the plane. This effect increases throw and reduces drop.

Isovel – a free jet of given momentum which then gives an established velocity profile.

Velocity pressure – pressure inherent in a moving air stream due to its velocity, expressed in Pa (N/m^2).

Static Pressure – pressure inside the duct which is available to overcome the frictional resistance.

Total pressure – sum of the velocity and static pressures.

2.0 Provision of ventilation in healthcare buildings

General requirements

Reasons for ventilation

2.1 Ventilation is essential in all occupied premises. This may be provided by either natural or mechanical means. The following factors determine the ventilation requirements of a department or area:

a. human habitation (fresh air requirements);

b. the activities of the department, that is, extraction of odours, aerosols, gases, vapours, fumes and dust – some of which may be toxic, infectious, corrosive, flammable, or otherwise hazardous (see Control of Substances Hazardous to Health (COSHH) regulations;

c. dilute and control airborne pathogenic material;

d. thermal comfort;

e. the removal of heat generated by equipment (for example in catering, wash-up and sterilizing areas and in some laboratory areas);

f. the reduction of the effects of solar heat gains;

g. the reduction of excessive moisture levels to prevent condensation (for example Hydrotherapy pools);

h. combustion requirements for fuel burning appliances (see BS5376, BS5410 and BS5440);

j. "make-up supply air" where local exhaust ventilation (LEV) etc is installed.

Influences on building layout

2.2 Mechanical ventilation systems are expensive in terms of capital and running costs, and planning solutions should be sought which take advantage of natural ventilation.

There is a statutory requirement to mechanically ventilate all enclosed work spaces.

2.3 It is acknowledged that planning constraints imposed by the building shape and/or functional relationships of specific areas will invariably result in some measure of deep planning thus minimising the opportunity for natural ventilation. However, ventilation costs can be minimised by ensuring that wherever practicable, core areas are reserved for rooms that require mechanical ventilation irrespective of their internal or peripheral location. Examples are sanitary facilities, dirty utilities and those rooms where clinical or functional requirements have specific environmental needs; and where for reasons of privacy, absence of solar gain etc, windowless accommodation is acceptable. Other spaces appropriate to core areas are those which have only transient occupation and therefore require little or no mechanical ventilation, for example circulation and storage areas.

Natural ventilation

2.4 Natural ventilation is usually created by the effects of wind pressure. It will also occur to some extent if there is a temperature difference between the inside and the outside of the building. The thermo-convective effect frequently

predominates when the wind speed is low and will be enhanced if there is a difference in height between inlet and outlet openings. Ventilation induced by wind pressures can induce high air change rates through a building, provided air is allowed to move freely within the space from the windward to the leeward side.

2.5 As the motivating influences of natural ventilation are variable, it is almost impossible to maintain consistent flow rates and thereby ensure that minimum ventilation rates will be achieved at all times. This variability normally is acceptable for general areas including office accommodation, general wards, staff rooms, library/seminar rooms, dining rooms and similar areas, which should be naturally ventilated, that is, provided with opening windows.

2.6 In all cases however excessive heat gain or external noise may preclude natural ventilation.

General extract ventilation systems

2.7 A general extract system will be required in rooms where odorous, but non-toxic fumes are likely, in order to ensure air movement into the space. Examples are therapy kitchens and beverage preparation rooms. A single fan/motor unit should be provided to meet this need.

Foul extract ventilation systems

2.8 A separate extract system will be required for sanitary facilities, lavage areas and dirty utilities, using dual motor/fan extract units with automatic change-over facilities to ensure that these rooms are maintained at negative pressure while the unit is in use.

2.9 Lavatories and dirty utilities should have an extract rate of 10 air changes/hour. Where WCs are located in bathroom spaces, the ventilation required for the WC will usually be adequate for the whole space.

Supply only ventilation

2.10 Mechanical supply ventilation should be provided in areas where it is important to maintain a positive pressure in a room, to prevent the ingress of less clean air, for example in clean utilities, or operating departments.

Supply and extract ventilation

2.11 Mechanical supply and extract ventilation should be provided in rooms where it is desirable to maintain the room at a neutral pressure at all times, such as treatment areas and plaster rooms.

Comfort cooling

2.12 Cooling is very expensive in terms of energy costs, and should be provided only where necessary to maintain a comfortable environment for staff and patient, or to ensure satisfactory operation of equipment.

2.13 Summertime temperature calculations using the method mentioned in paragraph 3.40, should be completed for all areas where there is a risk of excessive temperatures. Generally, air cooling should be provided where these calculations show that, without excessive levels of ventilation, internal temperatures are likely to rise more than about 3 K above external shade temperatures. In these circumstances, cooling should commence when the

space temperature reaches 25°C. Typical areas which may require cooling are some laboratories, central wash-up, and similar areas which are subject to high equipment heat gains. Where deep planning of other continuously occupied spaces, for example offices, is unavoidable, there will also be occasions when acceptable levels of comfort can only be maintained by air cooling. Planning solutions of this type, however, will be exceptional; and no provision for cooling plant will generally have been included in the Departmental Cost Allowance (DCA).

2.14 Refrigeration plant should be of sufficient capacity to offset heat gains and maintain areas at a temperature that does not exceed external shade temperatures by more than about 3 K.

Air-conditioning

2.15 Air-conditioning is only required in a very small number of areas within healthcare buildings; and due to the capital and running cost implications, its inclusion should be kept to a minimum.

2.16 Areas whose functions do warrant the installation of full air-conditioning, include operating departments, intensive therapy units, manufacturing pharmacies, and areas with sensitive equipment where the environment needs to be maintained within specified limits to prevent equipment failure.

Specialist ventilation

2.17 Due to the nature and extent of activities carried out in healthcare buildings, there are needs for a wide range of specialist ventilation systems. These types of system which are generally required in individual departments and typical arrangement are given in Chapter 6.

2.18 The activities within some departments will require the provision of local exhaust ventilation (LEV). This is a statutory requirement under COSHH wherever the escape of chemicals, toxic fumes, biological material or quantities of dust into the general area would present a hazard to the occupants.

Air scrubbing

2.19 Air scrubbing is the process by which air is recirculated through a filter in order to maintain airborne contamination at an acceptable level. An example of this is laminar flow cabinets.

Ventilation for general areas

2.20 Table 2.1 provides recommended air change rates, temperatures and pressures for general areas which require mechanical ventilation in healthcare buildings.

ROOM DESCRIPTION	TEMPERATURE (°C)		NOMINAL ROOM PRESSURE WITH RESPECT TO SURROUNDINGS	VENTILATION TYPES & RATE		
	SUMMER (IF COOLING)	WINTER		SUPPLY AC/h	GENERAL EXTRACT AC/h	FOUL EXTRACT AC/h
ALL DEPARTMENTS						
W.C.'S	-	18°C	-ve	-	-	10
BATHROOM/ SHOWER	-	21°C	-ve	-	-	6
LABORATORIES	Ambient+3°C	18°C	-ve	TO SUIT	ROOM LOADS	-
TREATMENT	25°C	21°C	0	10	10	-
STAFF CHANGE	-	21°C	+ve	3	-	-
COFFEE LOUNGE	-	18°C	-ve	-	3	-
BEVERAGE ROOM	-	18°C	-ve	-	5	-
DIRTY UTILITY	-	18°C	-ve	-	-	10
CLEAN UTILITY	-	18°C	+ve	6	-	-

Table 2.1 Typical internal design conditions
(Refer to Activity DataBase for specific details)

Acceptable methods

Use of natural ventilation

2.21 With the trend towards better sealed buildings, infiltration through building leakage has significantly reduced; and more attention is now given to the provision of purpose-made ventilation openings to achieve the necessary flow rates.

2.22 However, internal partitions, fire compartment walls and closed doorways can often impede the flow path, and when this happens, the process will be more dependent on single-sided ventilation. Nevertheless, even with this degree of compartmentation acceptable ventilation may still be achieved without window openings which would prejudice safety, security or comfort.

2.23 Some types of window, for example vertical sliding, can enhance single-sided air change by temperature difference, and these will improve the overall rate of natural ventilation in protected or sheltered areas where the effect of wind pressure is likely to be minimal.

2.24 It is generally considered that cross-flow ventilation is able to give reasonable air distribution for a distance of up to 6 metres inwards from the external facade, provided that reasonably clear air paths are maintained. Beyond this distance in areas where clear air paths cannot be maintained and in areas where high minimum air change rates are specified, mechanical ventilation should be provided. Section 2.3 of HTM 55 – 'Windows', BS5295 – 'Code of Practice for Design of Buildings' and CIBSE Symposium – 'Natural Ventilation by Design (2/12/80)' provide further information.

2.25 Where natural ventilation is adopted with complex air paths, the designer should produce an air flow diagram in order to ensure correct provision of air transfer devices.

Mechanical extract ventilation

2.26 Both foul and general extract systems can vary in complexity from a single wall-mounted fan for each facility, to a ducted air distribution system with dual extract fans.

2.27 Replacement air is either provided by a central supply system (as described below), or enters the building through gaps in the structure or purpose-made openings. Unless special precautions are taken, the latter may result in an unacceptable level of draughts occurring in winter, and possible risk of unacceptable levels of noise transmission.

2.28 If individual systems are used, the ventilation can be operated intermittently, provided it continues to run for at least 15 or 20 minutes after the room is vacated, as with light switch-operated fans in individual toilets.

2.29 If general exhaust systems are used, it is recommended that filtered and tempered replacement air is provided via a central supply plant to adjoining lobbies or corridors, to prevent the risk of discomfort caused by the ingress of cold air. Fire compartmentation requirements must be maintained.

2.30 Information on specialist extract systems is given in Chapter 6.

Mechanical supply systems

2.31 Where mechanical supply systems are required, the fresh air should be tempered and filtered before being delivered to the space, to avoid discomfort.

2.32 The air should be heated using a constant rather than variable temperature source, but generally only to the space air temperature. In most instances, the low pressure hot water heating (LPHW) should offset any fabric loss, so that set-back room temperatures can be maintained during unoccupied periods without the need for the ventilation system to operate.

Balanced ventilation

2.33 Balanced ventilation systems are merely a combination of a supply and extract system of equal volume; and either a single space or a whole building may be considered to be balanced. A balanced system is necessary in instances where it is essential to maintain consistent air movement within an area, for example treatment rooms.

Cascade ventilation

2.34 In operating departments it is normal practice to supply air to the operating room, and allow it to pass through to less clean areas – corridors, utility rooms etc from whence it is exhausted.

Recirculation systems

2.35 Due to the nature of the use of mechanical ventilation systems within healthcare buildings, there are few opportunities for the application of recirculation air systems.

2.36 Where the designer is considering the installation of a recirculation air system, due account must be taken of:

a. minimum fresh air supply volumes;

b. prevention of contamination of supply air from vitiated air in extract systems;

c. prevention of stratification occurring within mixing boxes which may result in freezing of downstream coils;

d. ensuring sufficient velocities through control dampers (ideally 5–6 m/s) to provide suitable authority; and good shut-off;

e. modulating control of mixing to provide optimum on-plant conditions;

f. use of "free cooling" by cycling the dampers to minimum fresh air when the enthalpy of the outside air is above that of the extract air under conditions when cooling is required.

Split comfort air-conditioners

2.37 Split comfort air-conditioners, room conditioning or cassette units are used increasingly where there is a small local requirement for cooling for operational purposes.

2.38 Until recently, the application of these units was restricted to single room but recent technological advances have led to the development of systems which allow multiple indoor units to independently provide either heating or cooling served by a single outdoor unit. These systems enable good temperature control of a number of rooms with maximum energy efficiency.

2.39 Split comfort air conditioners can often provide an effective economic solution to cooling needs, where a central refrigeration system is not practicable.

2.40 Whether single or multiple systems are used, it is essential that the designer gives due consideration to the provision of maintenance, the source of electrical supply and the environmental effects to the refrigerant used.

Dilution ventilation

2.41 Dilution ventilation may be appropriate under COSHH in certain circumstances, provided that the threshold limit values (TLV) are capable of being maintained without excessive air change rates. In addition, the source and distribution of the contaminents within the space must be reasonably uniformed. In cases where substances are highly toxic or where the rate of evolution is high, it is preferable to use local exhaust ventilation systems. These tend to give greater control of the substance and minimise the overall ventilation needs. Certain substances are regarded as too highly toxic for "ventilation control" and require devices such as "glove-boxes".

Mechanical ventilation systems

System selection

2.42 Natural ventilation is always the preferred solution for a space, provided that the quantity and quality of air required, and the consistency of control of ventilation to suit the requirements of the space, are achievable with this method. If this is not the case, a mechanical ventilation system will be required.

Choice of central/local plant

2.43 Mechanical ventilation is expensive to operate, and as such, should be controlled to operate when the space being served requires to be ventilated. In addition, loads on air-conditioning plant are rarely constant owing to changes in solar gain, occupancy and use of heat-generating equipment and lights, therefore control of temperature is critical.

2.44 If the variation of loads throughout a department or building are in phase, or are not significant, a central plant with single zone control can be adopted. However, this is rarely the case, and elsewhere, the condition or quantity of supply air to different areas or zones of the building must be varied accordingly. This can be done by providing either individual plants to each zone, or separate zone terminal control. Where there is a high density of rooms with similar ventilation requirements in an area of a building or department, it is usually economical to combine them into a central system.

2.45 In large buildings, a choice between a single distribution system and multiple smaller systems may arise. Large distribution systems and their plant can have the advantage of lower operating costs, but require more space for vertical shafts. In general, very long runs of ducting should be avoided to prevent undue heat losses or gains, excessive leakage, and difficulties in balancing during commissioning. As the pressure losses in the long runs will be greater and a higher initial static pressure will be required, this will lead to a more expensive class of ductwork. Multiple smaller distribution systems may be more expensive in capital and operating costs but they avoid long runs, large ducts and vertical shafts, and this may reduce overall building costs.

Zoning of the building

2.46 The efficiency and effectiveness of any ventilation or air-conditioning installation depends largely on the zoning and control of the installation. The factors to consider when determining the zoning of a ventilation system for a building or department are:

a. periods of occupancy;

b. fresh air/ventilation requirements;

c. smoke control.

2.47 Where the ventilation system is not merely tempering the air, but also providing the heating and/or cooling requirements, the following additional factors will need to be considered:

a. internal or peripheral location;

b. orientation of windows;

c. variation in internal loads;

d. level of control required.

Methods of control

2.48 The method of control selected for a ventilation system is governed to a large extent by the complexity of the system installed. The options available range from an electrical spur, to a building management system (BMS).

2.49 For single zone plant in staff areas, local control (with a run-on timer if required) is recommended, as this can be turned off when the space is not in use, thus saving both thermal and electrical energy. Most supply and extract systems, conversely, are required to operate continuously while the department is in use, thus some form of time control is necessary.

2.50 For most ventilation applications in healthcare buildings, the supply system is only required to temper the air, hence the supply temperature of the plant can either be maintained at a constant level, or controlled by a room sensor in an internal zone or return air duct (if applicable).

2.51 The control of individual plant items is covered in Chapter 4, with examples of typical control strategies in Chapter 5. For control of particular specialist ventilation and air-conditioning systems refer to Chapter 6 of this document.

Specific requirements for hospital departments

2.52 Specific requirements for individual spaces and departments are included in the Health Building Notes (HBNs) and Activity DataBase (ADB) A-Sheets.

3.0 Assessment of service requirements

Selection of design criteria

External design conditions

3.1 The most accurate data that is available for the summer and winter conditions at the site should be used.

3.2 As virtually all healthcare ventilation systems are "full fresh air" without recirculation, the majority of the load on the air-handling plant is in treating the incoming air. The plant therefore responds closely to the enthalpy of the outside air and is not influenced to a great extent by other factors.

3.3 To improve design accuracy the figures advocated herein (Table 3.1 and Figure 3.1) are based on long-term frequency distribution of **ambient enthalpy** (Legg and Robertson, 1976). The use of simultaneous occurrences of wet and dry bulb temperatures (enthalpy) avoids errors associated with choosing values from two independent frequency distributions.

Table 3.1 Outside design values

	Summer			Winter	
Location	Design enthalpy kj/kg	Associated temperature DB °C	WB sling °C	Design enthalpy kj/kg	Associated saturated temperature °C
Aldergrove	57	22–27	20.0	–1	–6.5
Boscombe Down	59	22–30	20.5	–2	–7.0
Croydon	61	26–29	21.2	–2	–7.0
Driffield	57	20–28	20.0	–4	–8.5
Elmdon	58	20–28	20.2	–4	–8.5
Kinloss	53	19–26	18.8	–5	–9.0
Lympne	61	22–28	21.2	–1	–6.5
Manchester	59	24–31	20.5	–2	–7.0
Mildenhall	62	22–32	21.5	–1	–6.5
Pembroke Dock	61	22–29	21.2	+2	–4.5
Renfrew	55	20–28	19.2	–4	–8.5
Stornoway	51	18–23	18.0	–1	–6.5
Turnhouse	54	20–26	19.0	–6	–10.0

The "design enthalpies" are values which are exceeded for 10 hours/year (0.11%).

The "associated temperature" values give the ranges of temperature which occur in association with the "design enthalpy" values. The higher value would be used for the calculation of fabric gains and for sizing air-cooled condensers, while the lower value is relevant to the design of cooling coils.

3.4 The enthalpy figures are also chosen such that they will be exceeded (higher in summer, lower in winter) for only 10 hours in the average year. This is a more accurate requirement that the CIBSE recommendation for ordinary buildings.

Figure 3.1 Location of sites for outside design values

3.5 For each summer design enthalpy, the possible range of temperature (dry bulb) is quoted. All figures quoted are "air" temperatures and enthalpies, and therefore pertain to areas shaded from the sun. Items of equipment located in direct sunlight, particularly when adjacent to sunlit surfaces, will be subjected to higher temperatures. Air-cooled refrigeration condensers are particularly vulnerable.

3.6 Local adjustments such as for height above sea level, or other climate peculiarities, should be made as appropriate.

3.7 For summertime temperature and cooling load calculations, the effect of orientation and the properties of building materials affect the sol-air temperature, and effective time; details must be obtained before calculations are undertaken.

Internal design conditions

3.8 A person's feeling of comfort depends on a complex combination of air temperature, radiant temperature, air movement, and humidity, together with personal factors such as clothing and activity. The non-personal factors have been combined together to produce a comfort index referred to as "Resultant temperature".

3.9 The choice of a suitable resultant temperature for system design resolves itself into choosing that temperature which should give optimum comfort for the occupants concerned, taking into account their clothing and level of activity. It must be remembered, however, that unless mechanical cooling is installed the internal air temperature can never be less than the external shade temperature.

3.10 Studies have shown that the majority of people will be neither warm nor cool in winter in rooms with still air (that is, the air velocity in the occupied zone is < 0.1 m/s) when the resultant temperature is between 19 and 23°C, and that levels of dissatisfaction do not increase when the temperature varies by within $\pm$ 1.5 K of the selected value.

3.11 It has also been found that there is a relationship between preferred indoor temperatures and mean outside temperature. Figure A1.2 in the CIBSE Guide indicates this relationship.

3.12 The design conditions selected within patient areas must strike a balance between the comfort requirements of staff and patients, who often have very different levels of clothing and activity. In areas such as operating departments, the comfort of the surgeon is of prime importance whereas in ward areas, the patient requirements are the overriding factor.

3.13 The effect of relative humidity on thermal comfort is less well defined than that of temperature. For most applications, the comfort range is between 40% and 70%, in order to minimise the build-up of static electricity; and allow for evaporation of perspiration.

3.14 Recommendations for the resultant temperatures and humidities of individual spaces are shown on activity data A-Sheets, but generally acceptable figures are given in Table 3.2.

Table 3.2 Internal conditions for design of plant

Season	Inside design conditions		Control range
	Dry bulb temp °C	% sat	
Winter heating	22	40 (nominal) + 5% – 0%	15 to 25°C
Summer cooling	20	60 (nominal) + 0% – 5%	15 to 25°C
Manual selection control	15 to 25°C max range obtainable at non-extreme external conditions only	50% sat minimum for using flammable anaesthetics + 5% – 0%	

Minimum fresh air requirements

3.15 For most applications involving human occupancy, the dilution of body odours is the critical factor in determining ventilation requirements; and where natural ventilation or full fresh-air systems are used, all ventilation air will be fresh.

3.16 Where odour dilution is the overriding factor, it is recommended that 8 litres/second/person should be taken as the minimum ventilation rate; however, this rises to 32 litres/second/person for rooms with heavy smoking (CIBSE Table B2.2).

3.17 In non-standard applications such as laboratories or operating departments, the particular requirements for each area should be considered independently in order to determine the overriding minimum requirement for ventilation.

Limiting supply air conditions

3.18 Where the ventilation system is used to maintain conditions within the space or pressure differentials between spaces, this requirement may exceed that for provision of fresh air. In these instances, recirculation systems can be used (if appropriate) in order to reduce the energy consumption of the system.

3.19 For most applications in healthcare buildings, it is the temperature differential between the supply and room air, rather than the actual temperature of the supply air which is the critical factor. The maximum recommended supply-to-room air temperature differential is:

summer cooling: – 7K
winter heating: + 10K

3.20 It is also necessary to maintain supply air humidity below 70% in order to minimise risks associated with condensation.

Air purity

3.21 In healthcare premises, the standard of filtration will depend on the activities within the occupied spaces. With the exception of special areas, (for

example manufacturing pharmacies), the requirement for aerobiological needs is not stringent, and filtration is only required to:

a. maintain hygienic conditions for the health and welfare of occupants, or for processes such as food preparation;

b. protect finishes, fabrics and furnishings, to reduce redecoration costs;

c. protect equipment either within the supply air system that is, to prevent blocking of coils, or in the space itself to prevent dust collection.

In these instances, an arrestance of 80% to 90% is acceptable, requiring an EU3 grade filter.

Humidity control requirements

3.22 Providing humidification is expensive in terms of plant, running costs and maintenance, and therefore its use should be restricted to where it is necessary for physiological or operational reasons.

3.23 The comfort band for humidity is wide; current practice recommends that it should be kept between 40% and 60% saturation.

3.24 Below 40% saturation, there is a tendency to feel dryness in the eyes, nose and throat, while static electricity increases, and organisms spore, making them more difficult to kill by means of surface disinfectants.

3.25 At humidity levels above 70%, there is increased risk of surface condensation and mould growth, and organisms are more likely to multiply.

Maximum noise levels

3.26 Noise will be generated in an air distribution system by the fan, ductwork fittings, dampers and grilles. Again, the specified maximum noise level will depend on the activities within the occupied spaces.

3.27 The overall noise level should be to levels set down in Hospital Design Note 4 'Noise control' amended by Health Notice HN (76)126, although general requirements are given in Table 3.3.

3.28 Attenuation should be incorporated into the ductwork system or plant arrangement as necessary to reduce noise from fans and plant items in order to achieve the acceptable limits within the rooms at the design air flows.

3.29 Plant noise should not be greater that 85 dBA within the plantroom from the fans, coolers, heaters, humidifiers etc, when starting up or running; and should be reduced to lower noise levels where the plant is near to departments sensitive to noise.

3.30 Attention must be given to the reduction of tonal components. High tonal components from air diffusers etc, can seriously disturb concentration over longer periods even when the overall noise level is low. Broadband noise causes less annoyance.

3.31 The values recommended in Table 3.3 are for the total noise environment of space. In general, there will be noise transmitted into the space and noise generated within the space. The designer requires knowledge of the total hospital layout and operational policies, to assign acceptance magnitudes to all the possible noise sources, in order to arrive at the correct rating.

Table 3.3 Interior noise level

Room	Overall noise level L_{10} Db(A)	Ventilation plant commissioning – Db(A)	Ventilation plant design – Db(A)
Operating room (ultra-clean)	see 6.96	–	–
Operating room (conventional)	50	45	40
Anaesthetic	50	45	40
Preparation	50	45	40
Scrub-up	50	45	40
Ward areas	35	30	30
Sanitary facilities	45	40	35
Industrial areas	50	45	40
Circulation areas	50	45	40

3.32 In Table 3.3 the overall noise level takes account of all internal and external noise sources. The commissioning noise level is the level measured with a sound level meter in the unoccupied room, taking account of the external noise together with the noise generated by the ventilation system. When occupied and in use, this commissioning level will constitute a continuous background noise which will allow the overall noise level to be achieved. The ventilation plant design noise level is that generated by the plant alone with no other noise source being considered. The levels suggested make recognised allowance for the ingress of environmental noise which must be considered in the overall design, that is, in specifying the attenuation of walls, partitions, ceilings, etc.

3.33 The recommended criterion is measured as the "a" weighted sound pressure level expressed in decibels, which should not be exceeded for more than 10% of the time.

3.34 The designer must also consider noise escaping to the external environment and this must not be unacceptable to occupants of adjacent buildings.

Calculation of building loads

Air infiltration

3.35 Air infiltration occurs due to a complex combination of wind pressures and thermal effects operating on a building, and is governed by the size and number of openings in the building envelope, and the complexity of internal air paths.

3.36 Table A4.4 in the CIBSE guide provides formulae for calculation of ventilation for a simple building; however, in general buildings where it is necessary to accurately calculate infiltration rates, solutions can only be obtained by computer modelling.

3.37 CIBSE Tables A4.12 and A4.13 give empirical values for typical buildings in normal use in winter. For non-standard applications, the infiltration chart (Figure A4.3) with the appropriate correction factors should be referred to.

3.38 When calculating thermal loads due to infiltration, based on Table A4.12, the following should be noted:

a. infiltration allowances may be halved during unoccupied periods;

b. where the majority of rooms have only single-sided ventilation, the load on the central plant will be roughly half the total of individual room loads;

c. if the ratio of openable doors and windows exceeds 25% on one wall only, the tabulated infiltration rate should be increased by 25%;

d. if the ratio of openable doors and windows exceeds 25% on two or more walls, the tabulated infiltration rate should be increased by 50%;

e. on severely exposed sites, the tabulated infiltration rates should be increased by 50%;

f. on sheltered sites, the tabulated infiltration rates should be reduced by 33%;

g. in rooms with mechanical supply systems, half the tabulated value should be used for calculations of room loads, to ensure that room temperatures can be maintained when the ventilation system is not operating.

Summertime temperatures

3.39 Summertime temperature calculations should be carried out for all rooms where the possibility of local solar or other heat gains may cause the temperature within an uncooled area to rise to an unacceptable level for the equipment and/or procedures to be carried out.

3.40 The calculation method for determining the summertime temperature is described in section A8 of the CIBSE guide; however, it is very important to select the time of day and time of year of peak loadings for the calculations, which is dependent upon the orientation and proportion of solar to total heat gain.

3.41 Where calculations indicate that internal temperatures frequently exceed external shade temperatures by more than 3 K, methods of reducing temperature rise should be investigated. Options include increasing ventilation rates, reducing gains, or providing mechanical cooling.

Peak heating load

3.42 Peak heating load calculations are necessary on all mechanical supply systems to establish the size of heater batteries and subsequently the central plant.

3.43 Where ventilation systems provide tempered air to spaces which have supplementary LPHW to offset the building fabric losses, the plant heating load should be calculated based on the external winter design temperature (selected from Table 3.1), the internal air temperature (given in activity data sheets, or selected from CIBSE Table A1.3), and the calculated total air volume (including a suitable allowance for leakage).

3.44 Where the ventilation system is the only means of heating a space, an increase in load equivalent to the calculated fabric heat losses from the space should be added to the ventilation load. A check of supply temperature difference should be made. If it exceeds 10% the ventilation supply volume should be increased.

3.45 If there are multiple heater batteries within a ventilation system, the size of each battery will be determined by the desired temperature rise across it.

Peak cooling load

3.46 Peak cooling load calculations are far more complex than heating load calculations.

3.47 In addition to the base data of air flow rates and temperatures, when calculating cooling loads, the engineer must take into account:

a. solar cooling loads;

b. surface conduction cooling loads;

c. internal gain cooling loads;

d. cooling loads due to high-level humidity control;

e. method of control of internal conditions;

f. fluctuations in internal temperatures.

3.48 When the peak internal loads have been assessed and a suitable allowance made for non-coincidence, the supply temperature may be calculated.

3.49 Once the lowest required supply temperature of the air handling unit has been established, and an allowance made for temperature rise through the fan and ductwork (usually 1 K for low pressure systems), the off-plant enthalpy can be established from a psychrometric chart or table.

3.50 The cooling load is calculated from the difference between the internal and external design enthalpies and total air flow.

3.51 The cooling loads for all plants on the chilled water system should be calculated at each of the individual peak times in order to accurately establish the required (diversified) capacity of the chiller.

3.52 Due to the complexity of the calculations and the necessity to perform multiple calculations, cooling load calculations computer modelling maybe helpful.

3.53 There is, however, a manual calculation procedure detailed in section A5 of the CIBSE guide, and a simplified approximate procedure detailed in Section A9.

Annual energy consumption

3.54 Annual energy consumptions of simple heating-only ventilation systems are simple to calculate, based on supply-to-external air temperature rise, and frequency of occurrence of external temperature data (CIBSE Table A2.8).

3.55 Air-conditioning systems are expensive to operate in terms of energy costs, when compared to standard heating systems.

3.56 The energy consumption of an air-handling unit is dependent upon:

a. external conditions;

b. internal control bands;

c. volume of air flow;

d. method of zoning and control.

3.57 Minimum air volumes are usually fixed by the room loads or fresh air requirements; however, the designer may increase air flow to some rooms or zones in order to balance loads, as detailed in paragraphs 3.70–3.71.

3.58 The method of zoning and control can significantly influence energy consumption.

3.59 The nature of air-conditioning operation, that is cooling and reheating for humidity or zonal temperature control, makes prediction of energy consumption very complex. It is imperative that these calculations are performed to ensure optimum energy efficiency.

3.60 Computer modelling is the preferred method however, a manual method is available, for example load and plant operation charts.

3.61 The concept of load and plant operation charts is outlined in CIBSE guide section B3. The method requires the designer to establish the minimum and maximum loads on all zones across the range of external temperatures between winter and summer design conditions. Once the load chart is complete, the plant chart converts the loads to supply temperatures, which are then superimposed on external air temperatures.

3.62 Humidity levels are plotted based on a mean condition line of dew-point temperatures, and the required supply dew-point temperature.

3.63 When all temperatures for all zones are plotted on the plant operation chart, set points and resetting schedules can be established. From this information, the outputs of individual heaters, coolers and humidifiers can be established at any given external temperature. When those loads are computed against annual frequency of occurrence of external temperatures as given in CIBSE Table A2.8, the annual energy consumption of individual elements, and thus the air-conditioning system, can be established.

Assessment of condensation risk

3.64 Condensation of water vapour occurs whenever a surface temperature falls below the ambient dew-point temperature.

3.65 The prediction of surface condensation on building elements such as walls windows and roofs can therefore be obtained by comparing the room dew-point and surface temperatures.

3.66 To undertake calculations on the risks of surface condensation, it is necessary to estimate the vapour pressure or moisture content of air within the building. This will largely be determined by the sources of moisture evaporation within the building, that is combustion of gas and other hydrocarbons; cooking, washing, bathing and other processes involving open vessels of hot water; and perspiration and respiration of building occupants.

3.67 In order to prevent surface condensation occurring, it is necessary to provide sufficient ventilation to maintain the maximum ambient dew-point temperature below the lowest surface temperature, the coldest surface usually being the glazing.

3.68 Where this would require excessive ventilation levels, the designer should consider removal of the moisture at the source of the evaporation via an exhaust hood or similar device.

3.69 In intermittently heated buildings, it is necessary to consider the condensation risk at night set-back conditions as well as during normal operation. Calculation methods for this assessment are given in section A10 of the CIBSE guide.

Calculation of plant requirements

Air supply volumes

3.70 The minimum air supply volume for a room is determined by the greater of the three criteria, viz:

a. minimum fresh air requirements (paragraphs 3.15–3.17); and

b. minimum supply volume for room loads for heating or cooling maximum supply temperature differential (paragraphs 3.18–3.20);

c. specific supply air volumes for dilution ventilation.

However, the air supply volume to individual rooms is often in excess of the minimum volume in order to enable a number of rooms to be supplied at the same temperature, that is, air volumes are increased to balance the zonal load in terms of energy per unit of supply air volume ($W/m^3/s$).

3.71 Multi-zone systems often do not have terminal cooling coils, and thus it is often necessary to balance the plant load in terms of cooling energy per unit of supply air volume ($W/m^3/s$) in order to prevent excessive overcooling and reheating occurring continuously on lightly loaded zones.

Plant sizing

3.72 Once the air flow has been established as described above, the cross-sectional area of the air-handling unit can be calculated based on a maximum coil face velocity of 2.5 m/s.

3.73 In order to establish the length of the air-handling unit, it will be necessary to refer to manufacturers' literature, ensuring all necessary access panels and components are included as detailed in Chapter 4.

3.74 The fan duty should be calculated by adding the resistances of all elements which contribute to the pressure drop of the index circuit.

3.75 The main elements which must be considered are:

a. inlet or discharge louvres;

b. plant entry and discharge;

c. attenuators;

d. components within the air-handling unit;

e. duct-mounted heaters and filters (including a dust allowance);

f. ductwork distribution;

g. ductwork fittings, including: fire dampers, volume control dampers, bends and sets, tees, changes of section;

h. air terminal device;

j. discharge velocity.

3.76 The pressure drops of louvres, grilles, external filters and attenuators may be obtained from the selected manufacturers' literature.

3.77 Where packaged air-handling units are installed, the fan pressure drop is usually quoted as external plant resistance, and thus the designer does not need to calculate the resistances of individual plant items. The designer should, however, ensure that an allowance has been made for filter clogging; and confirm whether the fan pressure quoted is fan total or static pressure.

3.78 Resistances of ductwork and fittings may be obtained from the CIBSE guide section C4; however, the designer should exercise some care when using tabulated pressure loss information for fittings which are relatively close together.

3.79 Upon completion of the resistance calculation exercise, the designer should make allowances for calculation and construction tolerances as indicated in Table 3.4.

Table 3.4 Typical fan volume and pressure margins

Criteria	Low pressure systems	Medium/high pressure systems
Volume flow rate margin for leaking and balancing requirements	+10%	+5%
Total pressure loss margin		
a. for increase in volume flow rate (above)	+10%	+5%
b. for uncertainties in calculation	+10%	+10%
Combined total pressure loss margin	+20%	+15%

Plantroom size and location

3.80 The ventilation plant and associated equipment should be positioned to give maximum reduction of noise and vibration transmitted to sensitive departments; and at the same time, achieve an economic solution for the distribution of services.

3.81 It is not recommended that noise and vibration generating plant be housed either directly above or below sensitive areas (for example operating or anaesthetic rooms) unless there is no alternative, in which case additional care and attention must be given to the control measures.

3.82 The plant must also be located so that it is remote from possible sources of contamination, heat gains and adverse weather conditions. The design should ensure that wind speed and direction have a minimal effect on plant throughput.

3.83 Access to and around plant is essential to facilitate inspection, routine maintenance, repair and plant replacement.

Provision of primary services

3.84 Where more than one air-handling plant requires cooling, remote central cooling plants with piped chilled water are preferred. In the case of a single plant, a multi-stage direct expansion cooling coil with refrigerant piped from an adjacent compressor/condensing plant could be considered. If this option is selected, a refrigerant gas detector mounted in the base of the duct and an alarm system audible to the end-user will also need to be provided (COSHH regulations).

3.85 Clean dry steam is preferred for humidification, provided that the boiler water treatment does not render the steam unusable for direct humidification.

3.86 When boiler steam is used, a warning notice regarding water treatment must be prominently displayed in the boilerhouse stating that the steam is to be used for humidification in the hospital air-conditioning plant; and that only approved additives must be used. Boiler treatments that comply to the Federal Drug Administration (FDA) Regulations 21: Part 173.310 and also **exclude volatiles** are considered suitable.

3.87 If a suitable supply of steam cannot be obtained from the steam main, a steam generator should be provided locally, or a self-generating humidifier installed. The location of a local steam generator is critical if condensate is to drain back into it.

Discharge and inlet sizing and location

3.88 Air intakes and discharge points are generally located at high level, to minimise the risks of noise nuisance to surrounding buildings, contamination and vandalism.

3.89 Each intake and discharge point should be protected from weather by louvres, a cowl, or a similar device.

3.90 Louvres should be sized based on a maximum face velocity of 2 m/s in order to prevent excessive noise generation and pressure loss.

3.91 Any space behind or under louvres or cowls should be tanked and drained if there is a possibility of moisture penetration.

3.92 Intake points should be situated away from cooling towers, boiler flues, vents from oil storage tanks, fume cupboards and other discharges of contaminated air, vapours and gases, and places where vehicle exhaust gases may be drawn in.

3.93 The discharge from an extract system must be located so that vitiated air cannot be drawn back into the supply air intake or any other fresh-air inlet. Ideally, the extract discharge will be located on a different face of the building from the supply intake(s). Where this is not practicable, there must be a minimum separation of 4 metres between them, with the discharge mounted at a higher level than the intake.

3.94 The discharge should be designed and located so that wind speed and direction have a minimal effect on the plant throughput; and should be fitted with corrosion-resistant weatherproof louvres to protect the system from driving rain, with mesh screens of not less than 6 mm and not more than 12 mm to prevent infestation. If possible, the inlet duct should slope back towards its intake, so that is self-draining. If this is not practicable, it should be provided with a drainage system.

Heat rejection devices

3.95 The design conditions given in Chapter 2 make no allowance for the elevated temperatures that can occur on the roof of buildings. Refrigeration condensers and cooling towers should, if practicable, be shaded from direct solar radiation, or the design adjusted to take account of the gain.

3.96 Air-cooled condensers must always be the first choice for heat rejection from any refrigeration plant. Evaporative cooling systems must not be used in healthcare premises unless limitations of space mean that they are the only way that the cooling load can be met. If they are used, the guidance set out in NHS Estates 'The control of legionnellae in healthcare premises – a code of practice' (HTM 2040) must be closely followed.

Air distribution arrangements

Ductwork distribution systems

3.97 Ductwork systems for ventilating and air-conditioning applications are referred to by their velocity or pressure category, that is, as low, medium or high velocity or pressure systems. HVCA limits are up to 10 m/s or 1000 Pa; 20 m/s or 1750 Pa; and 40 m/s or 3250 Pa in the case of conventional low, medium and high pressure systems respectively. High pressure systems are more expensive to install and because of their greater input power requirements, are increasingly more expensive to run.

3.98 For normal applications in healthcare buildings, low velocity systems are recommended; and the use of higher velocities than those recommended is not likely to be economical. Future trends are likely to be towards even lower optimum duct velocities; however, velocities lower than 2.5 m/s are unlikely to be justified.

3.99 The site will often dictate the main routing of ductwork systems, but in general the design should seek to make the layout as symmetrical as possible; that is, the pressure loss in each branch should be as nearly equal as possible. This will aid regulation and may reduce the number and variety of duct fittings that are needed.

Ductwork materials and construction

3.100 The choice of material to be used for the formation of a duct should take account of the nature of the air or gas being conveyed through the duct, the environment in which the duct will be placed, and the cost of the installation.

3.101 Galvanised sheet steel is generally suitable and most economical for normal ventilating and air-conditioning applications.

3.102 In instances where moisture levels and/or corrosive elements in the air being conveyed are very high, aluminium, stainless steel, PVC or GRP ducts should be used. Stainless or black steel are, however, the only suitable materials for high temperature ductwork.

3.103 Where builders' work ducts are used, these may be constructed of various materials; however, brickwork ducts must be rendered, and a greater allowance made for leakage.

3.104 Galvanised, black and stainless steel ductwork should be manufactured and installed to DW/142 – HVCA specification for sheet metal ductwork, but excluding the use of bolt-through supports.

3.105 GRP and PVC ductwork should be manufactured and installed to DW/151 – HVCA specification for plastic ductwork.

3.106 The inside of the ductwork should be free from structural projections and as smooth as possible. Flanged, gasketed joints are preferred.

3.107 Ductwork must be fire-stopped where it penetrates fire compartment walls, floors and enclosures, cavity barriers and sub-compartment walls or enclosures, and provided with weatherproof collars where roofs or external walls are penetrated.

3.108 In inherently wet areas, such as the base of fresh air inlet ducts, the ductwork may require draining to avoid any formation of water with the layout of any drains as specified for paragraphs 4.8 to 4.13.

Duct sections

3.109 Ducting is generally available in rectangular, circular and flat oval sections, although other sections may be made for special situations.

3.110 Rectangular ducting is most common on low pressure systems, for the following reasons:

a. it can readily be adapted to fit into the space available;

b. fittings are cheaper than those for circular or flat oval ductwork;

c. it can readily be joined to such component items as heating and cooling coils, and filters.

3.111 When sizing ductwork, the designer should take into account:

a. both installation and operating costs;

b. space limitations imposed by the structure and other services;

c. operating noise levels;

d. requirements of regulation at the commissioning stage.

3.112 For overall economy and performance, the aspect ratio should be close to 1:1, since high aspect ratios increase the pressure loss, heat gains or losses and overall cost (for example, changing the aspect ratio from 1:1 to 1:4 can typically increase the installed cost of the ductwork by 40% and add 25% to the heat gains or losses).

3.113 Rectangular ducting should not be the first choice for high pressure systems, and should be avoided in systems operating at high negative pressures, because the strengthening of the flat sides and the sealing requirements necessary to make rectangular ducts suitable for these high pressures are costly.

3.114 Circular ducting is preferable for high pressure systems; and for systems operating at high negative pressures. In the case of the latter, additional stiffening rings may be necessary. Machine-formed spirally-wound ducting and a standard range of pressed and fabricated fittings can sometimes make circular ducting more economical, particularly in low pressure systems having a relatively low proportion of fittings.

3.115 Flat oval ducting provides an alternative to circular ducting, principally where there is a limitation on one of the dimensions in the space available for the duct run.

3.116 Other sections may be used, such as triangular sections to pass through roof trusses. Such sections present difficulties in the provision of fittings, and

connections to standard plant items, and are likely to be more expensive than traditional sections.

3.117 Builder's work ducts and intake chambers should be surface treated and sealed to prevent dust particles being picked up by the airstream.

3.118 Flexible ductwork can be used for final connections to grilles and diffusers, provided it is constructed to meet the fire precautions recommended in CP413, that is the length of flexible ductwork branches is not greater than 3.7 metres; and does not pass through fire compartment walls, floors or enclosures of sub-compartment walls or enclosures, or through cavity barriers.

Standard ductwork fittings

3.119 All fittings should conform to DW142. Wherever possible, long radius bends, large radius main branches, not more than 45° angle sub-branches and long taper transformations shall be used.

3.120 Fittings should be arranged with vanes in sub-branches connected directly to grilles and diffusers, and turning vanes in square bends (when used).

3.121 The number of duct fittings should be kept to a minimum and there should be a conscious attempt to achieve some standardisation of types and sizes. Increasing the number and variety of fittings in a system can markedly raise its overall cost.

3.122 Bad design in relation to air flow can lead to vibration of flat duct surfaces, increases duct-generated noise and pressure loss, unpredictable behaviour in branch fittings and terminals, and adverse effects on the performance of installed plant items, such as dehumidifying coils.

Branches

3.123 There are many designs of branches and junctions in use. The important features are that the flow should be divided (or combined) with the minimum interference and disturbance. Changes in duct sizes should not be made at the branch but a short distance downstream (or upstream). A good dividing branch design cannot be effective if the flow entering the branch is not uniform across the section.

Changes of section

3.124 The expansion of a duct section should be formed with sides having a total included angle of no more than 30°, and preferably less than 20°. If the angle of expansion is greater, the flow is not likely to remain attached to the walls of the duct and large eddies will be formed with flow reversal at the walls. This leads not only to a high pressure loss, but also to a non-uniform velocity pattern at the outlet. Where there is insufficient space for a gentle expansion and a greater angle is necessary, internal splitters should be used.

3.125 A contraction in a duct section is less critical, but the total included angle of the taper should not exceed 40°, or 20° where the contraction is made on one side of the duct only.

3.126 The most economical way to change the section of a rectangular duct is to restrict the change of duct size to one side only. If the calculated reduction or increase to the side dimension is 50 mm or less, it is usually not economical to

change the size at that position. The minimum size of a rectangular duct should usually be 150 mm x 100 mm.

Other fittings

3.127 As a general rule, fittings should avoid abrupt changes in direction and sharp edges which cause the flow to separate and form eddies, thus limiting pressure loss and noise generation. If the fitting leads to the flow preferentially attaching to one side of the outlet, then a significant length of straight downstream duct is necessary before the next branch or fitting; this length should be greater than five equivalent diameters.

Noise generation within the ductwork

3.128 Noise is generated in ductwork at sharp edges, by tie rods, damper blades, duct obstructions and sharp bends etc. This air flow-generated noise becomes an important factor if it is about the same or greater level than the upstream noise level. Air flow-generated noise is often referred to as re-generated noise.

3.129 The noise level generated by air flow in ductwork is very sensitive to the velocity. The sound power of this noise is approximately proportional to the sixth power of the velocity; that is, a doubling of the duct velocity will increase the sound power by a factor of 64 (or about 18 dB). The duct velocities should therefore be kept as low as possible. In general, duct fittings which have lower pressure loss factors in similar flow conditions will generate less noise.

3.130 Ductwork serving quiet areas should not be routed through noisy areas, where noise break-in can occur and increase the noise level in the ductwork.

3.131 Grille register and louvre noise should be kept to the minimum by selecting types having low noise-producing characteristics, without high tonal noise; and should be fitted with acoustically treated external inlet and outlet louvres.

Volume control damper locations

3.132 Manually operated balancing dampers are needed generally:

a. in the main duct downstream of the fan;

b. in branches of zone ducts;

c. in sub-branch ducts serving four or more terminals;

d. at terminals not covered by (c) above.

3.133 Dampers integral with terminals should only be used for final trimming of air volumes, or noise and air distribution problems may ensue.

3.134 Dampers in rectangular ducts should be single-bladed up to 450 mm longer side and opposed-blade multi-leaf type above this size. In circular ducts, iris-type dampers are recommended, provided there is enough space round the duct for the damper housing. Dampers must be accessible and have a quadrant plate with locking screw. Dampers should be located as far away as possible from adjacent branches or plant items.

Fire damper types and locations

3.135 Smoke-diverting dampers must be provided on recirculation air systems to automatically divert any smoke-contaminated return air to the outside of the building in the event of a fire; and arranged so that the normally open smoke-diverting damper on the return air branch to the input unit closes and all the return air is exhausted through the extract fan. Guidance is available in HTM 81 and BS5582:Part 9.

The Building Standards (Scotland) Regulations and Scottish Home and Health Department – Fire Safety: New Health Buildings in Scotland HMSO 1987; see letter reference SHHD/DGM (1988)61 and (1990)67.

3.136 It is essential that all relevant fire aspects of ducting systems are agreed with the fire officer before the design is finalised.

Access door locations

3.137 Access doors are required to facilitate access to plant items and ductwork components for inspection, maintenance, cleaning and replacement, and must be of sufficient size to permit access for the required functions.

3.138 Recommended locations for access doors are given in DW/142, and are generally provided to give access to:

a. every regulating damper;

b. every fire and motorised damper;

c. filter (to facilitate filter withdrawal);

d. both sides of cooling/heating coils;

e. humidifiers;

f. fans and to provide access to motors and impellers.

3.139 Care should be taken when siting access doors to ensure that no other services to be installed will prevent reasonable access.

Diffuser and grille selection and sizing

3.140 The effectiveness of all ventilation and air-conditioning systems depends on the methods by which air is introduced to, and vitiated air is removed from, the space. The usual results of poor air terminal selection and/or positioning are draughts, stagnation, poor air quality, large temperature gradients and excessive noise.

3.141 Air can be supplied to a space in a number of ways, although any device can be broadly placed into one of two categories: that producing a diffused supply, or that producing a perpendicular jet. Diffusers may be radial or linear, and normally utilise the Coanda effect to reduce the risk of excessive room air movement. A perpendicular jet is formed by discharging air though grilles, louvres or nozzles, which are generally adjustable.

3.142 Air flow patterns produced by both types of terminal are dependent to a large extent on the presence of the Coanda effect (that is, adhesion of the air stream to an adjacent surface).

3.143 Supply air terminals can be incorporated into any room surface, for example floors, walls (high or low level), desk top etc.

3.144 As they operate on the jet principle, the use of side wall and linear grilles is restricted to areas where air change rates are low, that is, less than 10 per hour. Linear perforated or rectangular diffusers can provide acceptable

conditions within the occupied zone at up to 15 air changes per hour. In areas where a higher air change rate is required, circular diffusers should be used.

3.145 The performance of supply air terminal devices is provided, based on three criteria: throw, spread and drop. Throw is defined as perpendicular or parallel distance from the terminal to the point at which the air velocity is 0.5 m/s isovel. Spread is defined as the width of the 0.5 m/s isovel; and drop is defined as the vertical distance from the centre line of the terminal to the bottom edge of the 0.25 m/s isovel.

3.146 It is necessary to consider each of these parameters in both summer and winter conditions to ensure satisfactory operation of the air terminal device, as warm jets behave very differently from cold jets.

3.147 A warm jet tends to rise until it attaches itself to a horizontal surface, while a cold jet falls. Care must be taken to ensure that this does not lead to unacceptable temperature gradients in winter, or excessive air velocities in the occupied zone in summer.

3.148 In order to ensure satisfactory air movement within a space, it is necessary to consider interaction between air movement from adjacent terminals, and ceiling mounted fixtures (light fittings etc), as well as interaction between air movement and room surfaces.

3.149 If the supply and extract terminals are too close, short circulating may occur, while if they are too far apart, stagnant zones may be formed. Where two opposing air streams meet, the individual velocities must not be greater than 0.25 m/s.

3.150 Supply and extract grilles and diffusers should be fitted with opposed-blade dampers for fine balancing purposes.

3.151 Further guidance on the selection of grilles and diffusers is given in Section B3 of the CIBSE guide.

Transfer grilles size and location

3.152 Transfer grilles are required in locations where there is a significant imbalance between the supply and extract rates in a room, to relieve any pressure differentials which may affect the operation of the spaces and/or the ventilation system. Minor air flows can be catered for by leakage around doors and frequent opening.

3.153 While air transfer grilles in walls, partitions or doors etc are not strictly part of the ventilation system, they form essential components of the building's air distribution.

3.154 Care needs to be taken to ensure that the positioning of transfer grilles does not interfere with the fire or smoke integrity of the building. In general, the air transfer grilles should not be installed within fire-resisting boundaries, although if this is unavoidable, these should be fitted with fire or smoke dampers.

3.155 Where installed, transfer grilles should be of the non-vision type, sized for a maximum face velocity of 1.5 m/s.

Pressure relief damper size and location

3.156 Pressure relief dampers are required in lieu of air transfer grilles in areas where it is necessary to maintain pressure differentials between adjacent rooms to prevent reversal of air flows (for example in operating theatre suites and clean rooms).

3.157 Fire precautions for pressure relief dampers are the same as transfer grilles (see paragraphs 3.135–3.136); and for sizing criteria, refer to Chapter 6 (operating departments).

3.158 Where installed, pressure relief flaps should be of the balanced blade type, with fine adjustment of relief pressure settings; and should give a seal as tight as practicable when closed.

Thermal insulation

3.159 Thermal insulation is applied to ductwork to reduce heat exchange, and to prevent condensation.

3.160 In a duct system, the air temperature changes can be significant, especially when passing though untreated space, and these have the effect of reducing the heating or cooling capacity of the air and of increasing the energy input to the system. The heat transmission to and from the surrounding space can be reduced by effective insulation of the ducts.

3.161 Condensation can arise in ductwork systems conveying cooled air and, apart from creating conditions conducive to corrosion of ductwork, condensation affects the heat and vapour-resisting properties of insulating materials themselves and this induces further condensation.

3.162 In normal circumstances, the insulation thickness for heat resistance is sufficient to prevent surface condensation, but in extreme conditions the insulation thickness for vapour resistance may be greater than that for heat resistance. When cold ducts pass through areas of high dew-point, carefully selected vapour barriers should be applied externally to the insulation.

4.0 Plant equipment selection

General requirements

Air-handling unit construction

4.1 The basic technical requirements of the whole of the ventilation system should meet the requirements of Model Engineering Specification C04 – 'Mechanical ventilation and air-conditioning systems'; and fire precautions should be incorporated in accordance with Firecode.

The Building Standards (Scotland) Regulations and Scottish Home and Health Department – Fire Safety: New Health Buildings in Scotland HMSO 1987; see letter reference SHHD/DGM (1988)61 and (1990) 67.

4.2 Guidance is available in HTM 81 and BS5588:Part 9.

4.3 The plants should have a high standard of airtightness. The double-skin method of construction with insulation sandwiched between two metal faces is recommended.

4.4 The inside of the plant should be as smooth as possible with no channels, rolled angles or formed sections that could trap or hold moisture. If stiffeners are required, they should be fitted externally. Internal bracing may be fitted provided it is of a design that will not trap or hold moisture.

4.5 Access must be provided adjacent to filters, cooling and heating coils, heat recovery devices, attenuators and humidifiers to facilitate easy cleaning and maintenance (see individual plant items).

4.6 Airflow across air treatment components such as filters, heat exchangers and humidifiers will be influenced by the pattern of the approaching airstream; and if unsatisfactory conditions are created, the performance of the component will be reduced.

4.7 The height of the air-handling unit (AHU) must provide sufficient ground clearance to enable the installation of a drainage system as described below.

AHU drainage system

4.8 All items of plant that could produce moisture must be provided with a drainage system.

4.9 The drip-tray should be constructed of a corrosion-resistant material and be so arranged that it will completely drain. To prevent "pooling", it is essential that the drain connection should not have an up-stand; and that a slope of approximately 1 in 20 in all directions should be incorporated to the drain outlet position. The tray must be easily removable for inspection and maintenance.

4.10 The trap need not be directly under the drainage tray, provided that the pipework connecting the two has a continuous fall. Each trap should be of the clear (borosilicate) glass type to show (visibly) the integrity of the water seal, and should be provided with a means for filling. A permanent marker on each trap should be provided to indicate the water seal level when the system fan is running at its design duty. Each installation should incorporate quick-release couplings to facilitate removal of the traps for cleaning.

4.11 Traps fitted to plant located outside or in unheated plantrooms may need to be trace heated in winter. The trace-heating must not raise the temperature of water heated in the trap above 5°C.

4.12 Pipework from each trap outlet should be thermoplastic, copper or stainless steel tube. Stainless steel could be particularly useful in situations requiring mechanical strength (glass is not necessary). The pipework should be a minimum diameter of 22 mm and have a minimum fall of 1 in 60 in the direction of flow and be well supported.

4.13 Water from each trap must discharge via a type A air gap, as specified in BS6281:Part 1, above the unrestricted spill-over level of either an open tundish connected to a drainage stack via a second trap, or a floor gully (or channel).

Layout of plants

4.14 The plant must be arranged so that the majority of items are under positive pressure. It is preferable that any item of plant requiring a drain be on the positive pressure side of the fan. A recommended layout is given in schematic form in Figure 4.1.

4.15 Flexible joints should be provided at fan inlet and outlet connections; should be equal in cross-section to the points of connection; and should not be longer than 200 mm or shorter than 100 mm.

4.16 Separate extract plant will generally be required for the area served by each supply plant. If applicable, energy recovery equipment should be fitted and provision made for the fitting of a grade EU2 panel filter to protect it.

Provision of dampers

4.17 Motorised non-return dampers should be located immediately behind the intake and discharge of each supply and extract system respectively. They should be of the opposed blade type, opening through a full 90°; and must close automatically in the event of power failure or plant shutdown to prevent any reversal of air flow.

4.18 The quality of motorised dampers is critical. They should be rigid, with square connections fitted with end and edge seals of a flexible material and with minimal play in linkages. The leakage on shut-off should be less than 2%.

4.19 A manually operated isolating damper should be installed between the main plant and its distribution system, to enable the plant to be isolated when cleaning is in progress.

4.20 A main volume control damper should be provided in the main plant, to set the design flow rate during commissioning. The damper must be capable of being locked in any position. If it is intended to use it for plant isolation also, it must be capable of being reset to give the design air flow without the need for re-measurement.

Health and safety aspects

4.21 It is essential that the main plant ductwork is located far enough from the floor to permit the correct installation of drainage systems for cooling coils, humidifiers and heat recovery systems. Easy access for maintenance of drainage systems and their associated pipework must be provided.

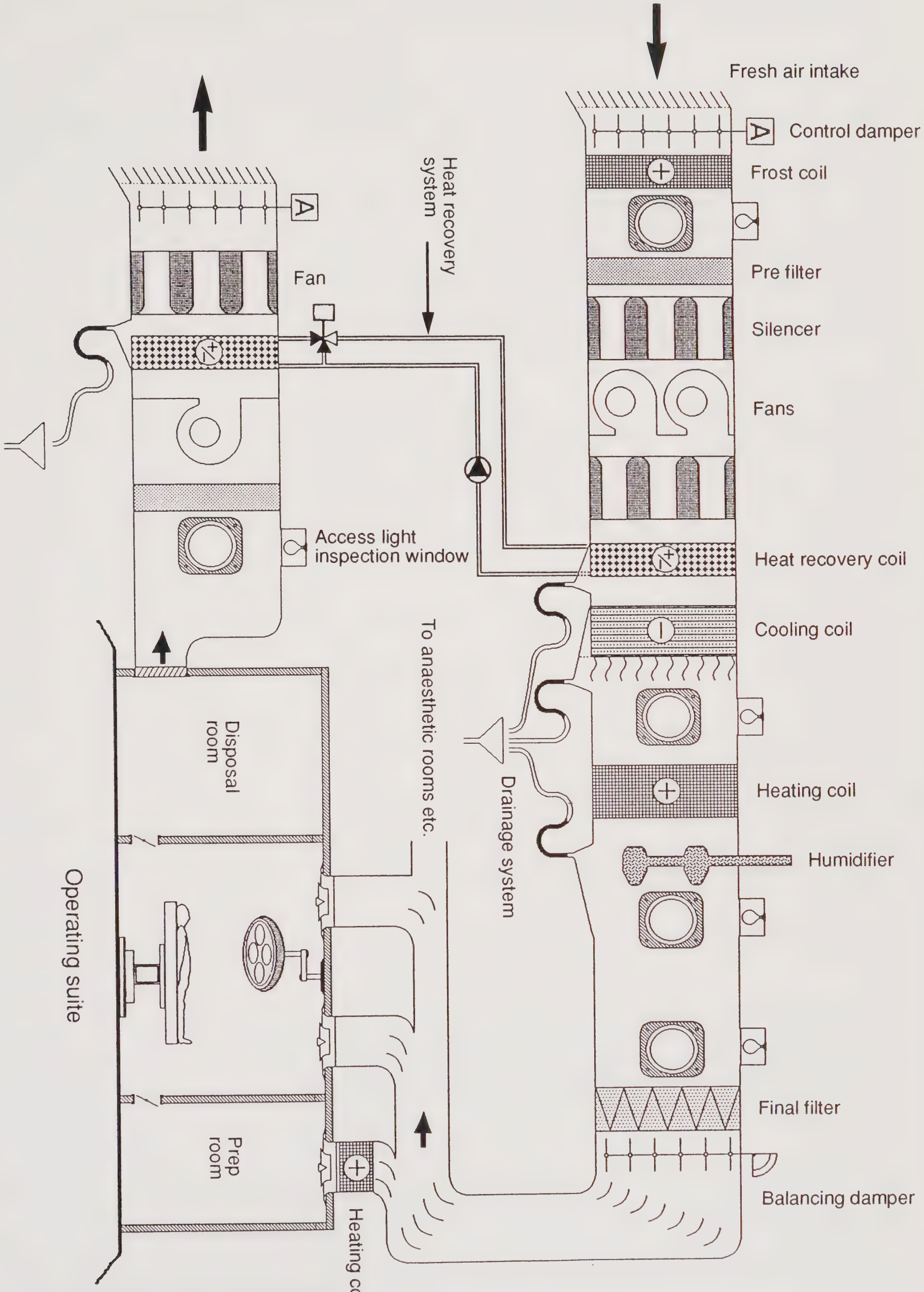


Figure 4.1 Typical operating suite ventilation system

4.22 Organic materials or substances that can support the growth of micro-organisms must not be used in the construction of the plant or its distribution system. The water fittings and materials directory lists suitable materials for sealants and gaskets.

4.23 The plant and its distribution system must not contain any material or substance that could cause or support combustion.

Vibration

4.24 Vibration from a remote plantroom can be transmitted by the structure of the building, may be regenerated and may sometimes be magnified many times. Plant should be selected to have the minimum vibration generation and should be installed on suitable anti-vibration mounts. Pipe and ductwork should incorporate anti-vibration couplings, preferably in two planes at right angles, as close to the vibration source as possible. Consideration should also be given to anti-vibration pipe hangers and supports.

Sequence of components

4.25 Generally, the following arrangement of plant components should be used, although in many instances not all components are required:

a. fresh air inlet;

b. control damper;

c. frost coil;

d. pre-filter;

e. silencer;

f. fan;

g. cooler coil;

h. heater coil;

j. humidifier;

k. control damper;

m. final filter.

There may, however, be instances where this arrangement is not appropriate; and the plant arrangement should be planned accordingly.

Fans

General requirements

4.26 The fan should be selected for good efficiency and minimum noise level, but the overriding factor should be the selection of a fan characteristic such that the air quantity is not greatly affected by system pressure changes due to filters becoming dirty or external wind effects.

Acceptable types

4.27 Fans can be of the axial, centrifugal, cross flow, mixed flow or propeller type, depending upon the requirements of the system.

4.28 Where used, centrifugal fans should preferably be of the backward blade type, and give an efficiency of not less than 78%. Alternatively, where noise

levels are more critical and pressure requirements are lower, forward curved blade fans are acceptable. For high power applications, aerofoil blade fans may be appropriate.

Selection

Forward curved centrifugal fans can overload if allowed to handle more air than they are designed for.

4.29 Generally, large ventilation systems will always use centrifugal fans due to their efficiency, non-overloading characteristics, and developed pressures.

4.30 Alternatively, it may be appropriate to use mixed flow fans in high pressure systems.

4.31 Axial flow or propeller fans are generally only used in local through-the-wall systems, or systems with low pressure requirements.

4.32 Cross-flow fans have very low operating efficiencies, and thus their use is restricted to applications such as fan coil units.

Fan location and connection

4.33 Fans can be positioned to either "blow through" or "draw through" the central plant. The main advantages of a blow-through unit are:

- a lower supply air moisture content can be achieved;
- the cooling coil and humidifier drains will be under positive pressure.

4.34 The consequent disadvantages of this arrangement are:

a. there is greater risk of condensate leakage through the casing of the cooling coil;

b. an additional plant section is required at fan discharge to reduce the velocity before the next plant component.

4.35 The fan performance figures given by manufacturers in their catalogue data are based on tests carried out under ideal conditions, which include long uniform ducts on the fan inlet/outlet. These standard test connections are unlikely to occur in practice, the designer should therefore ensure as far as is practical that the fan performance will not be significantly de-rated by the system. This objective can be approached by ensuring that the fan inlet flow conditions comprise uniform axial flow velocities with low levels of turbulence.

4.36 Where the outlet duct is larger than the fan discharge connection, there should be a gradual transition, with a following section of straight duct having a length equivalent to three duct diameters.

4.37 The design of the fan inlet connection must be carefully considered to avoid swirl in the airstream. When the air spins in the same direction as the impeller, the performance and power consumption of the fan are reduced. When the air spins in the opposite direction to the impeller the power consumption and noise will increase with hardly any pressure increase. Airstream swirl is usually induced by large variations across the fan inlet eye caused by the air passing round a tight bend immediately before the eye.

4.38 For any condition in which a centrifugal fan is located with a free inlet, the clear distance between the suction opening and the nearest wall should be not less than the diameter of the inlet. If two fans with free inlets are positioned within the same chamber, their adjacent suction openings should be at least 1.5 diameters apart.

Control

4.39 Fans in healthcare applications are generally either single or two-speed. Where there is a requirement for two-speed operation, this is generally via a local user control (for example in a hood extract system to provide a boost facility) or via a time schedule for energy saving during unoccupied periods.

4.40 Where two-speed operation is required, twin supply fans may be preferred, as they allow greater flexibility of plant control and avoid the need for spare motors to be provided. If single-speed fans are selected, speed reduction will be required to reduce the flow rate by 50% during set-back as detailed elsewhere.

4.41 Where there is a requirement for stand-by fans, (for example in foul extract systems), the system should incorporate an automatic changeover facility activated via an air-flow sensor, and fault indication should be provided.

Requirements for particular applications

4.42 Where the system air is explosive, aggressive, or has a high moisture content, the extract fan motor should be located outside the air stream. This is generally achieved with axial fans by using a bifurcated unit.

Heater batteries

General requirements

4.43 Fog/frost heating coils should not be protected by filters. They should therefore be constructed in plain tubing without fins and be as near to the outside as possible to minimise condensation during cold weather. Access for cleaning must be provided.

4.44 Finned tube coils should be constructed of solid drawn copper pipe, generally connected in parallel, with aluminium fins. In instances where the atmosphere is particularly corrosive, copper fins should be used.

4.45 Where there is a wet heating system in the areas served, the main heater battery should be sized for the ventilation requirements only, not for the fabric loss.

Acceptable types

4.46 Electric, water or steam heater batteries may be considered; however, electric heater batteries are expensive to operate and where there are alternatives, their use should be restricted to low power use, for example trimming control.

4.47 If steam supplied heater batteries are used, for example, their venting, trapping and condensate systems must be designed so that a vacuum cannot occur within the coil and nor will the condensate back up due to excessive back-pressure in the condensate main.

Location

4.48 The standard arrangement of heater batteries in air-handling units is given in Chapter 3.

4.49 Where possible, wet trimmer heater batteries should be located in plant areas.

4.50 Where it is necessary to locate heater batteries in false ceilings etc, consideration should be given to the use of electric heaters. If this is not practicable, drip-trays should be installed under both the battery and the control valve assembly to protect the ceiling.

Control

4.51 Water heater batteries should be connected to a constant temperature heating circuit. Fog/frost coils should be controlled by an off-coil temperature sensor operating a two or three-port motorised valve to provide a minimum plant "on temperature" of between 2°C and 5°C. The off-coil temperature of the frost coil is generally sensed by a serpentine thermostat laid across the downstream face of the coil or upstream of the next plant item. This thermostat will shut the fan down if any part of the air stream is below the minimum set-point.

4.52 The main heater battery should be controlled in the same manner under the dictates of either an off-coil temperature sensor, or a room temperature sensor, depending on the plant configuration and method of control. Trimmer heater batteries are generally controlled by one or more averaging temperature sensors within the room or rooms served by the zone.

4.53 Various options for control of single and multi-zone air-conditioning systems are given in section B3 of the CIBSE guide.

4.54 It is usual to open the pre-heater, and close other heater batteries on system shutdown or fan failure.

Cooling coils

General requirements

4.55 Eliminator plates are required to be fitted downstream of the coil if face velocities exceed 2.25 m/s.

4.56 Cooling coils will need to be periodically decontaminated. The downstream access door should be glazed and have a low-voltage weatherproof light fitting provided for maintenance purposes. The light fitting should be mounted so that its bulb can be changed from outside the duct.

Acceptable types

4.57 All cooling coils must be fitted with their own independent drainage system. A baffle or similar device must be provided in the drip tray to prevent air bypassing the coil and the tray should be large enough to capture the moisture from the bends and headers.

4.58 Where coils are greater than 1 m high, intermediate drip-trays are required.

Selection

4.59 Care must be taken in selection to minimise electrolytic action resulting from condensation on the air side. Coils constructed from copper tubes with copper fins extended on the downstream side in the form of an eliminator, and

electro-tinned after manufacture are preferred. All parts of the coil and its associated ductwork in contact with moisture must be manufactured from corrosion-resistant materials. Stainless steel, GRP or plastic finishes are preferred.

Location

4.60 Micro-organisms which multiply in moisture cannot be avoided when the coil is dehumidifying, but the risk of infection will be reduced by locating the final filter downstream of the coils.

4.61 The standard arrangement of cooling coils in air-handling units is given in Chapter 3.

Control

4.62 There are two basic methods of control for cooling coils:

a. off-coil control – used in multi-zone systems or single-zone systems where close humidity control is required, to provide a constant maximum off-plant condition which satisfies the temperature and high humidity requirements of the zone with the highest load;

b. sequential control – used in single-zone systems, or multi-zone systems with averaging sensors where close control is not required. A room or duct temperature sensor controls the cooling coil and heater battery in sequence to maintain constant room conditions.

4.63 The advantage of off-coil control is that accurate humidity control can be provided without relying on humidity sensors, which are prone to inaccuracy and drift.

4.64 Off-coil control is, however, expensive to operate in terms of energy consumption, due to the fact that there is no feedback of room loads, and thus at low loads and in systems where there are large zonal variations, significant over-cooling and reheating will occur.

4.65 On systems with two-speed operating, it is usual to isolate the cooling coil upon selection of low speed. In addition, on system shutdown, low air flow or fan failure, the cooling coil must be isolated.

Humidifiers

General requirements

4.66 The most important requirement for a humidifier is to create complete mixing of the steam with the air; and the manufacturers' instructions should be followed regarding minimum distances which should be allowed before bends or other components.

4.67 The number and length of steam injection manifolds to be used is dependent on various factors such as duct cross-section area, air velocity, air dry bulb temperature and manifold design.

4.68 Adequately sized glazed access doors and low-voltage swimming-pool type weatherproof bulkhead light fittings are essential for maintenance purposes. The light fittings should be mounted so that their bulbs can be changed from outside the duct.

4.69 All parts of the humidifier and its associated ductwork in contact with moisture must be manufactured from corrosion-resistant materials. Stainless steel, GRP or plastic finishes are preferred.

4.70 The cleanliness of the water supply is essential for the safe operation of humidifiers. Provision should be made for draining down supply pipework and break tanks for periodic disinfection and for periods when they are not required in service.

4.71 The addition of treatment chemicals for continuous control of water quality for humidifier/air handling units should be avoided. Consideration could be given to installing a UV system to control microbiological growth. Given the limitations of UV systems, however, this will require filtration to high quality to ensure the effectiveness of exposure of organisms to the UV irradiation. As with all water treatment systems the unit should be of proven efficacy and incorporate UV monitors so that any loss of transmission can be detected.

4.72 All humidifiers must be fitted with their own independent drainage system as detailed in paragraphs 4.8–4.13.

Acceptable types

4.73 Steam injection manifold-type humidifiers are considered suitable for use in health building air-conditioning systems.

4.74 Steam may be derived from the central steam supply, or generated locally either within or adjacent to the humidifier.

4.75 The introduction of steam should be by an appliance specially designed to discharge dry steam into the air-conditioning system without objectionable noise or carry-over of moisture.

4.76 During the design stage, consideration should be given to the proposed methods for the regular cleansing of the humidifier(s) and their components.

4.77 Ultrasonic humidifiers are available. The action of ultrasonic frequencies should not be considered an effective method for control of micro-organisms. The supply of water to the humidifier should be free from viable bacteria. The humidifier reservoir is accessible to micro-organisms, including legionellae, carried by the incoming air, and the water temperature in the humidifier during operation may be such as to encourage growth of these bacteria; biofilms may form. These units are capable of producing aerosols that may transmit legionellae.

Selection

4.78 A mains steam humidifier can be noisy, and will be difficult to control if it is operated at an excessive steam pressure. It should be sized for an operating pressure of approximately 1 bar; and the pipework supplying it should be provided with a dirt pocket, pressure reducing valve and steam trap installed as close as practicable to the humidifier, so that the steam condition at entry is as dry as possible. A temperature switch on the condensate line (or equivalent design provision by the humidifier manufacturer) should be incorporated to prevent "spitting" on start-up.

4.79 Most operational problems with mains steam humidifiers arise because of back-pressure in the condensate discharge line. Unless the condensate from

the device can be discharged and collected at atmospheric pressure, it should be discharged directly to drain.

4.80 A local steam generator, where used, must be fed with potable quality water. Additional water treatment to the standard set out above may be required. If the humidifier is unused for a period exceeding 48 hours, it must automatically drain its water content, including that contained in the supply pipework, right back to the running main and leave itself empty.

4.81 Some generators are of a type that requires regular cleaning and descaling. The design must allow for them to be installed such that they can be physically isolated from the air duct in order to prevent contamination of the supply by cleaning agents while this is taking place.

Location

4.82 Careful siting of the humidifier lance is required to prevent the steam impinging onto the side(s) of the duct, condensing and generating excess moisture.

4.83 It is essential to position the humidifier upstream of the final attenuator, with at least 1 metre unobstructed air flow downstream.

Control

4.84 Accurate humidity control can only be provided on single-zone systems, or multi-zone systems with zonal humidifiers. In the above systems, humidity sensors control the humidifier for low-level humidity control, and override the temperature controls to open the cooling coil valve for high-level humidity control.

4.85 Multi-zone systems are more usually controlled by a minimum humidity sensor located in the supply duct(s) following the last heater battery.

4.86 Overriding controls separate from the normal plant humidistat should be installed. Their purpose is to prevent excessive condensation when starting up. A time delay should be incoporated into the humidifier control system such that the humidifier does not start until 30 minutes after the ventilation/plant start-up. In addition, a high limit humidistat should be installed to switch off the humidifier when the saturation reaches 70%. This humidistat is to control added moisture; it is not necessary to install a de-humidifier to reduce the humidity of the incoming air if it already exceeds 70%. The normal humidifier control system should ensure that the humidifier is switched off when the fan is not running.

Filtration

General requirements

4.87 The purpose of filtration is to reduce the level of airborne contamination entering a building, and is generally carried out in one or two stages.

4.88 General ventilation supply plant should incorporate air filters of grade EU3, sized for a maximum face velocity of 2.5 m/s. Coarse pre-filters may be justified where the intake air is exceptionally polluted. Extract filtration will only be required where heat recovery devices are installed, or contaminated air is required to be filtered prior to discharge to atmosphere.

4.89 In urban or other areas of high atmospheric pollution, a higher standard of filtration may be justified to reduce the level of staining to internal finishes.

4.90 Filters must be securely housed and sealed in well-fitting frames, readily accessible for replacement, and must be provided with a differential pressure indicator.

4.91 Neither the filter media, nor any material used in the construction of the filters, should be capable of sustaining combustion; and the filter media should be such that particles of the media do not detach and become carried away by the air flow.

4.92 A complete spare set of filters is required to be provided by the contractor at handover.

Acceptable types

4.93 A grading system based on arrestance and efficiency has been introduced by Eurovent (the European Committee of the Manufacturers of Air Handling Equipment) and is shown in Table 4.1.

4.94 "Arrestance" is a measure of the total weight of synthetic dust captured by a filter. The weight of dust caught is expressed as a percentage of the total weight of dust entering the filter. "Arrestance" provides a good indication of a filter's ability to remove the larger, heavier particles found in outdoor air. It is used, primarily, as a measure of the performance of the lower grade filters, as indicated in Table 4.1.

4.95 Efficiency of a filter is measured as the percentage of microscopic particles removed from the air stream by the filter, and is used to grade high-performance filters, as indicated in Table 4.1.

Table 4.1 Eurovent filter grades

Filter grade	Arrestance (A)	Efficiency (E) %
1	A < 65	
2	65 < A < 80	
3	80 < A < 90	
4	A > 90	
5		40 < E < 60
6		60 < E < 80
7		80 < E < 90
8		90 < E < 95
9		E < 95

4.96 All filters should be of the dry type. Panel filters are cheap and disposable with relatively low dust-holding capacity, and are generally used as pre-filters to eliminate large particles which would otherwise clog or cause damage to the fan and coils.

4.97 Where a higher standard of filtration is required, secondary bag filters should generally be used.

Most filter companies no longer supply automatic roll-type filter housings, although they are continuing to supply replacement filters for existing installations.

4.98 Where installed as pre-filters, automatic roll type fabric filters should be of the dry type (grade EU2), be operated automatically by an electric motor under the dictates of a pressure differential switch, and include a visual indication of the end of the roll. All filters develop a higher resistance to air flow with the build-up of dirt, and this governs the effective life of the filter. Filters should therefore be selected for optimum dust holding capacity, however, this may often only be finally determined from the plant history.

Selection

4.99 Some general guidance on the application of the various grades of filter is given in Table 4.2

Table 4.2 Filter applications

Grade	Application
2/3	Pre-filters and filters for systems serving areas not requiring any great degree of cleanliness, such as toilet supply systems and light industrial applications.
4	For application as main filters where low to moderate cleanliness is required.
5	Main filters for general applications where decor protection is not critical. Suitable for paint-spray installations.
6	As 5, but with added decor protection. Intermediate filter to extend life of a HEPA main filter.
7	As 5, but for use where protection of decor is particularly important. Typically, operating room.
8	High protection from dust staining, suitable for computer room and other areas containing electronic equipment.
9	For high-quality filtration but where HEPA filters are not justified, for example Class 3 clean room applications.

4.100 In addition to the nine grades of filter already described, there is another classification known as High Efficiency Particulate Air (HEPA) filters, sometimes known as absolute filters. They are designed to provide very high-efficiency filtration of tiny particles in the sub-micron size range.

4.101 HEPA filters are expensive, and their use should be kept to a minimum. Where used, HEPA filters should be of the replaceable panel type with air-proof seals. Areas requiring HEPA filters include ultra-clean ventilation (UCV) suites and manufacturing pharmacies.

Location

4.102 The primary filter will be positioned on the inlet side of the fan, downstream from the frost coil. It is essential, however, that when fitted, the secondary filter is on the positive side of the fan to prevent air being drawn into the system after the filter, and after any item of equipment which could shed particles.

4.103 The filter installation must be arranged to provide easy access to filter media for cleaning, removal or replacement, with side or front withdrawal as required.

Control

4.104 Differential pressure transducers should be provided to monitor and alarm on excessive filter pressure drop.

Heat recovery

General requirements

4.105 Where recirculation of air is not permitted for operational reasons, there is a significant risk of discharging large quantities of useful energy in extract air. Heat recovery must be considered in all ventilation system design, to assess the useful value of energy discharged in relation to the cost of recovery of such heat. For most systems in healthcare premises, either a "run-around" system of heat exchangers, a thermal wheel or a plate type unit may be appropriate.

4.106 A full economic assessment of the benefits and costs of heat recovery should be carried out prior to inclusion of heat recovery in a ventilation system.

4.107 Where a local comparable heat demand can be supplied economically by thermal reclamation, heat recovery equipment should be installed. Where extracted air has a high moisture level, the cooling effect on the extract air may require drains for condensate and access for cleaning heat exchangers. Selection should be based on efficiency, maintenance requirements and the practical reliability of the preferred system. Run-around coils offer ease of installation in either new or existing plantrooms and, like plate heat exchangers, require little maintenance.

4.108 Where heat recovery devices are installed, they should be protected on the extract air side by a grade EU2 filter to prevent clogging, fitted in accordance with the requirements of paragraphs 4.87–4.101.

This subject is covered in Energy Efficiency 'Heat recovery from ventilation systems'.

Location

4.109 Heat recovery devices should be installed with an upstream filter on the extract side, and prior to the cooling coil or main heater battery on the supply side.

Control

4.110 It is essential to consider the control of both the heat recovery device and the fog/frost coil when assessing the economics of heat recovery, as all energy provided by the frost coil will directly reduce the heat exchange of the heat recovery device. To this end, the off-coil setting of the frost coil should be the minimum possible to protect the primary filter (around 2°C).

4.111 The heat recovery device should be controlled in sequence with the main heater battery, and should incorporate a control to prevent the transfer of unwanted heat when the air-on condition rises above the required plant set-point.

4.112 In instances where the plant is cooling the air, it may be possible to remove heat from the supply air at high ambient conditions under the dictates of enthalpy comparators in the intake and discharge ducts.

Attenuation

General requirements

4.113 Noise will be generated in an air distribution system by the fan, plant items, and air flow. The ductwork is a very effective transmitter of this noise, hence there is generally a need to limit the noise transmission to meet the requirements of the building. This normally involves the provision of sound attenuation treatment as part of the overall ductwork system design.

4.114 A thorough assessment of the design should be made to assess the noise problem and sound treatment requirements and this should take into account the following primary factors:

a. fan and plant noise generation;

b. air flow generated noise in ductwork fittings and dampers;

c. noise generated at grilles, diffusers and other terminals;

d. noise break-in and break-out of ductwork;

e. cross-talk and similar interference;

f. the noise limitations for the building and surrounding areas;

g. external noise generation.

4.115 A method of assessment of these factors and the sound attenuation requirements of ductwork systems is given in section B12 of the CIBSE Guide.

4.116 The fan is usually the main source of system noise. The sound power that it generates varies as the square of the fan pressure, and thus to limit the fan noise level the system resistance should be kept as low as economically possible. As a general rule the selected fan should operate close to its point of maximum efficiency to minimise its noise generation. Where there is disturbance to the air flow at the fan inlet, the manufacturer's stated fan noise levels should be increased by up to 5 dB. More precise guidance on this aspect may be available from fan manufacturers.

4.117 Noise break-out from all equipment housed in the plantroom must be taken into consideration if control is to be satisfactory. Any ductwork within the plantroom after the silencer should be acoustically insulated to prevent noise break-in.

4.118 There is no complete means of control over external noise generation from such as road traffic, aircraft, factory and community noise. Consideration must be given to this at the design planning stage.

4.119 The Department of Health has issued Health Building Notes, Health Technical Memoranda, Hospital Design Note No 4 supplemented by Health Circular HN (76)126, and a Data Sheet on Noise and Vibration Control (DH 1.2), which should be consulted for detailed guidance.

Acceptable types

4.120 The noise levels produced by ventilation and other plant should be reduced by using duct silencers. These reduce fan noise generated within the duct systems and also control noise break-out to the atmosphere. It should be noted that duct silencers offer a resistance to air-flow. The resistance must be included in the fan and ductwork calculations.

4.121 The construction of the sound-absorbing in-fill should be suitable for the quality of air being handled. The duct silencer acoustic in-fill should be protected by a perforated sheet metal casing. Absorption of moisture, dirt and corrosive substances into the "in-fill" and the release of fibrous particles into the airstream should be prevented by the use of a plastic membrane.

Selection

4.122 Provided care is taken in the design and construction of low pressure systems to avoid significant noise generation in the ductwork, attenuation should only be needed to absorb fan noise.

4.123 Cross-talk attenuators may be necessary where noise intrusion between adjacent spaces can arise and where individual room confidentiality is required.

Location

4.124 It is always preferable to control noise and vibration at source, or as close to source as possible. This may be achieved in the equipment specification and selection at the design stage and usually results in a lower cost than corrective measures.

4.125 Fans radiate noise through both the inlet and outlet connections and it may be necessary to provide attenuators to limit the noise from both of these connections.

4.126 Attenuation or other sound-absorbing material should not be applied to the inside surface of the duct system after the final filter, owing to the risk of mechanical damage and the subsequent dispersal of the media into the ventilation system.

4.127 In addition, attenuators should be located so that insulation is not nearer to a fire damper that one metre and is not fitted anywhere after the final filter.

Requirements for particular applications

4.128 Rooms in operating departments typically have hard surfaces for hygienic reasons. This makes the room acoustically very live, that is, the reverberation times will be long. Due account must be taken of both the direct noise and the reverberant (diffuse) noise from any source in the room.

5.0 Automatic control

General requirements

Requirements for automatic control

5.1 The basic requirements for an automatic control system are as follows:

a. facilities to start, set-back and stop the plant;

b. temperature control and indication;

c. humidity control and indication;

d. alarms to indicate plant failure, low air flow, and filter state.

5.2 The designer should consider whether it is necessary for the supply and extract fans to be interlocked, either so that the supply fan will not operate unless airflow is established within the extract system, or vice-versa depending on required pressures within rooms being served.

5.3 This will be particularly important in laboratory and pharmacy areas that also contain fume cupboards, safety cabinets and LEV systems.

5.4 Alarms should be provided to show "filter fault" and "low air flow". The "filter fault" alarm should in initiated by a predetermined increase of pressure differentials across the filter. The "low air flow" alarm should be initiated when the supply air quantity falls to 80% of the design value.

Objectives of control system

5.5 The primary object of a ventilation or air-conditioning plant control system is to maintain the space served within the required environmental control bands, at the appropriate times, regardless of external conditions or internal loads.

5.6 It is the task of the designer to select a control system to achieve the above with minimum energy consumption.

Selection of control system

5.7 Air-conditioning plants are both complex to control and expensive in terms of energy costs. This makes them ideal for microprocessor or intelligent control.

5.8 With developments in building management systems (BMS), it is often cost-effective to provide intelligent controls in lieu of conventional analogue controls for air-conditioning plants, whether or not there is a general site BMS system.

5.9 Often, it is not possible to accurately predict building load variation at the design stage, and thus optimum set points cannot be assessed. Information provided by monitoring the operation of the plant via a BMS system will enable optimum set points to be established and energy consumptions reduced.

Location of controls

5.10 Whether within the plant, duct or room, sensors should be located to provide accurate measurement of the condition of the air being monitored.

5.11 Sensors and control items such as control valves should be located close to the element being sensed or plant item being controlled, in order to minimise time lags within the system which may create over-shoot of conditions beyond the design envelope and result in additional energy consumption.

5.12 Specific activities will require continuous or intermittent mechanical ventilation, and where the latter occurs, frequently at a high air change rate, for example in bathrooms and treatment rooms, sufficient prominence in position and type should be given to the local control of this facility to encourage economical use.

Time switching

Requirements for time switching

5.13 Facilities to start, set-back and stop the plant should be provided in the plantroom. Remote start and set-back control and indication, if required, should be provided at a manned staff location, for example at the reception or staff base.

5.14 Where two speed controls are installed, the set-back facility for each plant should depress the control temperature to around 15°C; exclude any humidification and cooling from the system; and reduce the supply and extract air volumes by around 50%. Provided any desired direction of air movement from clean to less clean can be maintained, it may be possible to turn the associated extract fan off during set-back.

Methods of time switching

Start-up control

5.15 The plant start control should contain a control logic that will start the plant in the sequence set out in the algorithms in Tables 5.1 and 5.2.

Set-back control

5.16 If a two-speed fan or twin supply fans are used, the volume can be reduced to 50%, and the control temperature set point depressed to around 15°C when spaces are in the set-back position.

5.17 The chosen method will depend on the likely usage and economic advantages of the system. Provision should be made to lock out the alarms when on set-back and to interlock the extract fan, humidifiers, cooling coils, main and trimmer heaters with the fan so that they cannot operate when the air system is off. See also the control algorithms in Tables 5.3 and 5.4.

5.18 The fire control panel should have restricted access for the fire officer and include independent on/off control and indication of the supply and extract.

Environmental control

Temperature control methods and application

General

5.19 All control valves must fail safe, that is, close in the event of power or air-flow failure, with the exception of the fog/frost battery control valve, which should open upon power or air-flow failure.

5.20 A suggested arrangement for controlling heating and cooling batteries is shown in Figures 5.1 and 5.2. Complete plant control algorithms showing their interrelationship with the rest of the control system are shown in Tables 5.1 to 5.4.

Room temperature control

5.21 The limits for room temperature set point are generally between 16°C and 25°C depending on the particular application; and in some specialised instances (for example operating departments) are selectable by the user.

5.22 The selection of temperature set point for each room or zone, may be by a control facility in the room or zone, or remotely at the control panel or BMS system. The control device should be marked "raise" and "lower", and should control within the specified air temperature range with a tolerance of ±1 K. All other control set points must be selectable in the plantroom and the BMS system (where installed).

5.23 Where local control is provided, an indication of temperature will be required locally, or at a staff base (if appropriate), using an analogue or digital indicator. This may be mounted in a supervisory control panel, with the signal repeated in the plantroom or on the BMS system.

Frost coil control

5.24 Steam supplied fog/frost batteries must be operated as on/off devices with their sensor mounted upstream of the battery. This will give "open loop" control; a set point of +1°C is recommended.

5.25 Low pressure hot water (LPHW) supplied frost batteries should be controlled using the Proportional mode. Their sensor should be located downstream of the battery to give "closed loop" control. A set point of 2–5°C is recommended.

5.26 If the temperature downstream of the frost battery, as sensed by a serpentine thermostat, falls below the required set point over any part of the coil, the plant must automatically shut down in order to prevent damage to the other batteries.

Off-plant control

5.27 The control logic must prevent the chiller and pre-heater being on at the same time. It should also never be possible for the chiller and humidifier to be on at the same time.

Humidity control methods and application

5.28 In order to prevent excessive condensation when starting up from a total plant shut-down, a time delay should be incorporated into the control system such that the humidifier does not start until 30 minutes after the ventilation/plant start-up.

5.29 Irrespective of the method of control, a high-limit humidistat should be installed to ensure that the condition of the air in the duct does not exceed 70% sat, particularly during plant start-up.

5.30 With certain types of steam humidifiers, it may be necessary to install a thermostat in the condensate line from the humidifier's steam supply, to ensure that the steam at the control valve is as dry as possible before it is injected into the air supply.

5.31 The humidifier and cooling coil control must be interlocked so that they cannot be on at the same time.

5.32 The humidifier control system should ensure that it is switched off with the fan. It is preferable to design the control system so that the humidifier is isolated for an adequate time before the fan is turned off so as to purge humid air from the system.

5.33 All control valves must fail safe, that is, close in the event of power failure, and the humidifier must be interlocked with the low air-flow switch.

5.34 Suggested humidifiers plant control algorithms showing their interrelationship with the rest of the control system are shown in Tables 5.1 to 5.4.

Multi-zone control methods and application

5.35 Control of all air-conditioning parameters is difficult to achieve with multi-zone systems, since each zone requires reheater and humidifier to give total control of humidity (assuming reheat for each zone).

5.36 It is therefore usual with multi-zone systems to provide control of zonal temperature only, with humidity control based on average conditions within all zones, or minimum conditions within one zone.

5.37 Where there is a requirement for control of air-conditioning parameters in a number of areas, consideration should be given to providing separate plants for each area in order to avoid the need for expensive over-cooling and reheating of individual areas or zones.

5.38 Most multi-zone systems within healthcare premises are controlled based on off-coil control within the central plant, with terminal heater batteries on individual zones.

Alarms and indication

5.39 Supply and extract systems should include indicator lamps on plant room control panels to confirm the operational status of each system. Where the usage is on a regular daily pattern, a time switch control with manual over-rider for a limited period should be considered.

5.40 Where a system is provided for a particular space, the indicator should be in, or immediately adjacent to that space and local controls should be provided with labels clearly defining their function.

5.41 The "plant failure" and "low airflow" alarm should be initiated by a paddle switch or other device located in the main air supply duct. This should operate when the air quantity fails to reach or falls to around 80% of the design value and will give indication of fan failure, damper closed, access door left open, or any other eventuality that could cause a reduction of air quantity.

5.42 The "filter fault alarm" should be initiated by a predetermined increase of pressure differential across the filters, thereby indicating a dirty filter.

Inclined gauge manometers must be installed across filters to give maintenance staff a direct indication of their condition.

5.43 Visual indication should be provided at a manned staff location, for example the reception or staff base, and in the plantroom to show "plant failure", low air flow and "filter fault".

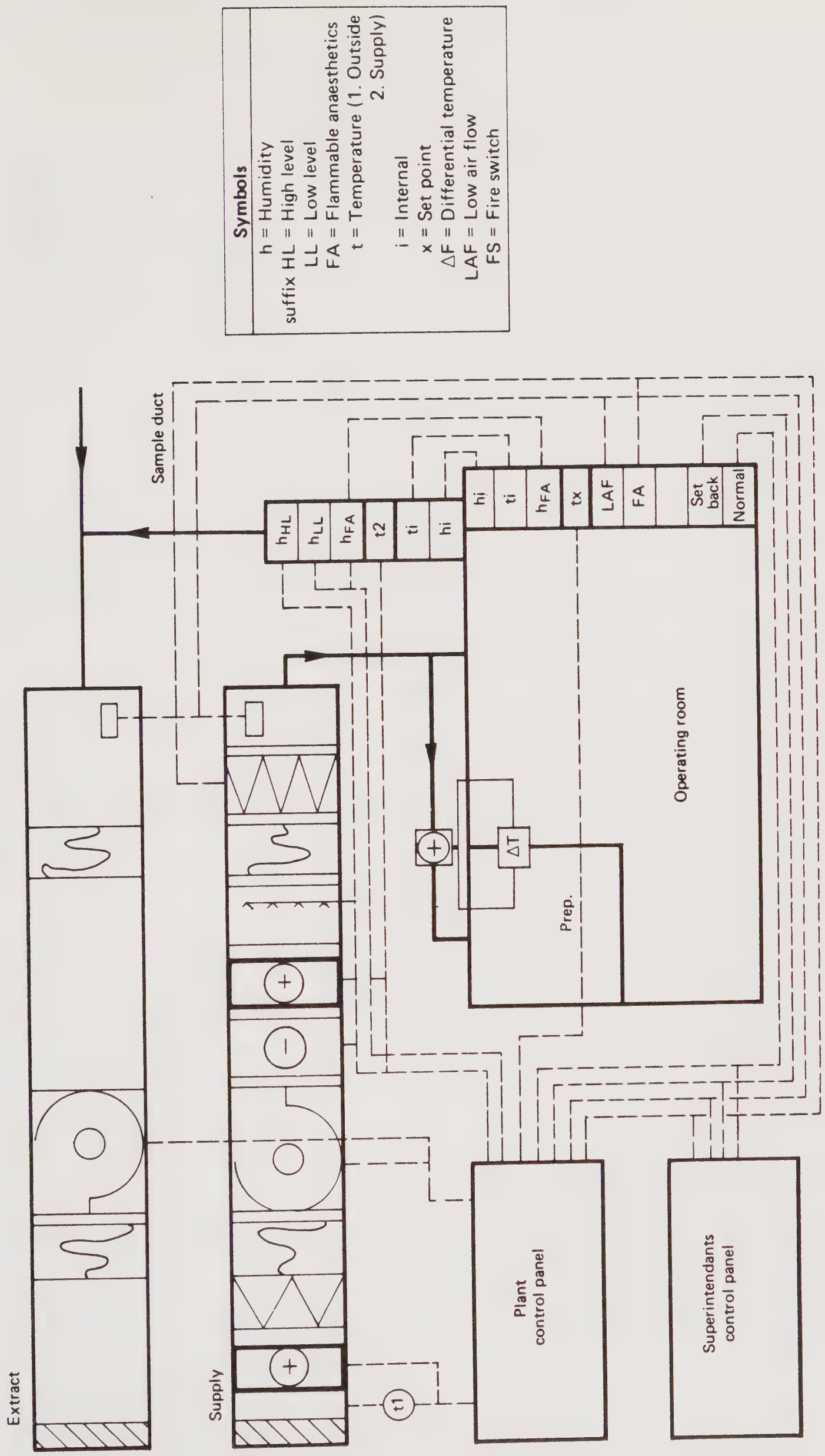


Figure 5.1 Control system

System	Control	Set point	Control status	Operation
Frost coil	t_1	5°C	$t_1 < 5°C$	
Cooling coil	t_2	t_x	$t_2 > t_x$	
Cooling coil	h_{HL}	$60\ ^{+0}_{-5}$ sat.	$h_{HL} > 60\%$	
Heating coil	t_2	t_x	$t_2 < t_x$	
Humidifier	h_{LL}	$40\ ^{+5}_{-0}$ sat.	$h_{LL} < 40\%$	
Humidifier	h_{FA}	$50\ ^{+5}_{-0}$ sat.	$h_{FA} < 50\%$	Flammable anaesthetics
Prep. heater	ΔT	0°C	± 1°C	
Set back see 6.10	t_2	15°C	50% air vol cooling/hum-off	Op room
Fire switch	FS	–	Manual fan selection	Plant room Op dept
Plant	On/off	–		Plant room Op dept
Indication temp.		ti		Op room
Indication % sat.		hi		Op room
Flow alarm		% flow	alarm > 80%	
Filter alarm				Replace filter

Figure 5.2 Control and indication schedule

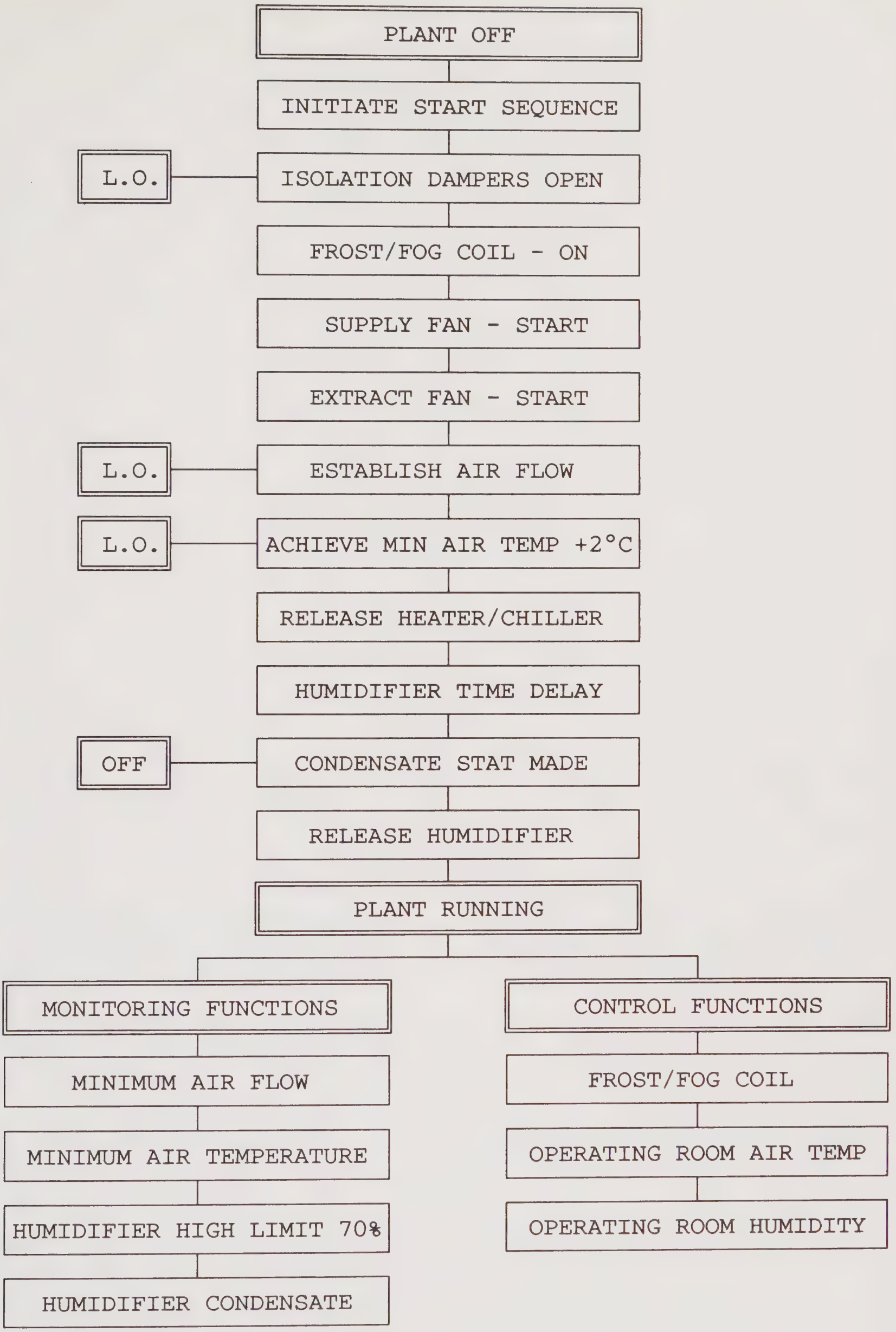


Table 5.1 Typical plant control algorithm – normal start-up sequence

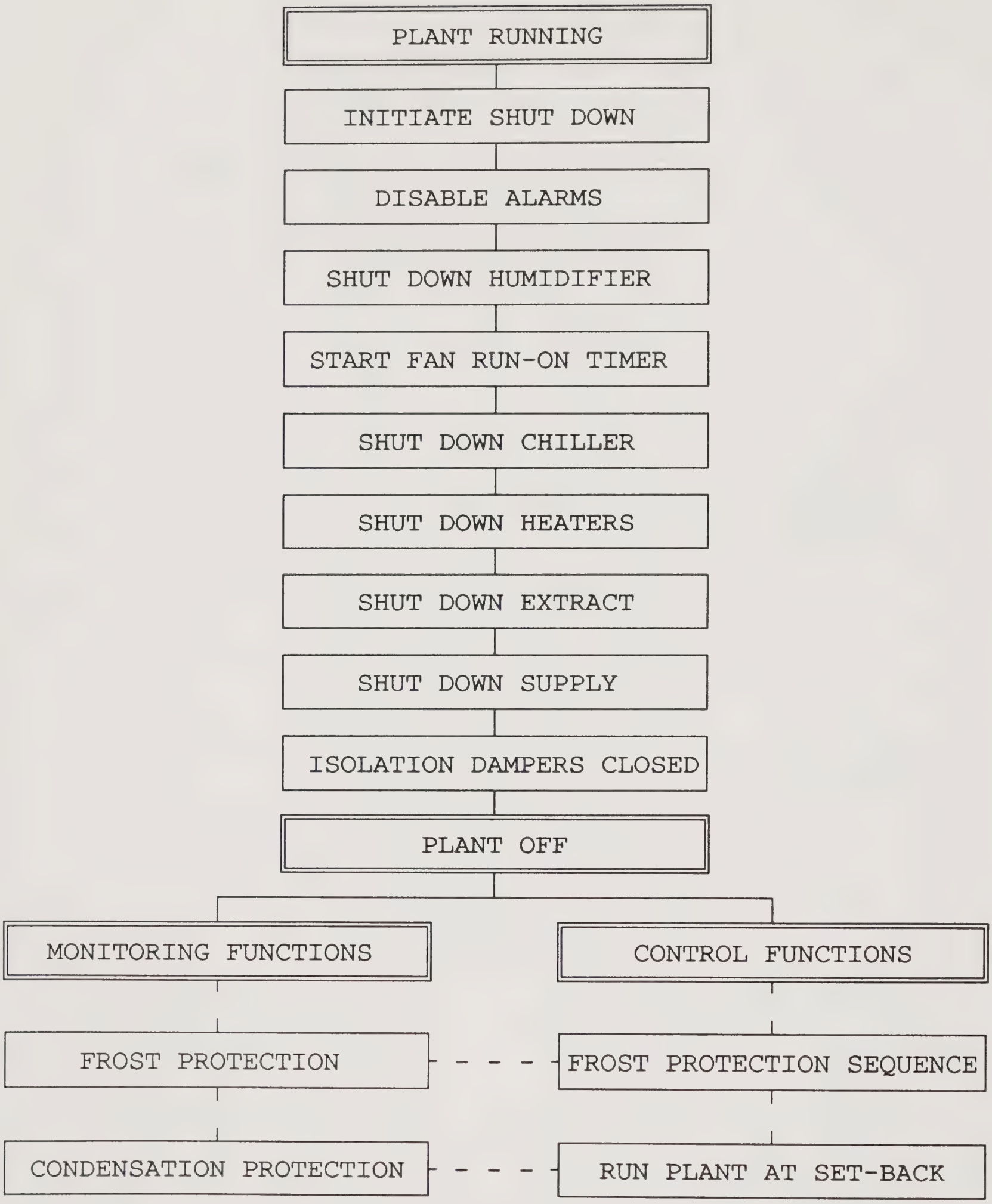


Table 5.2 Plant control algorithm – normal shut-down sequence

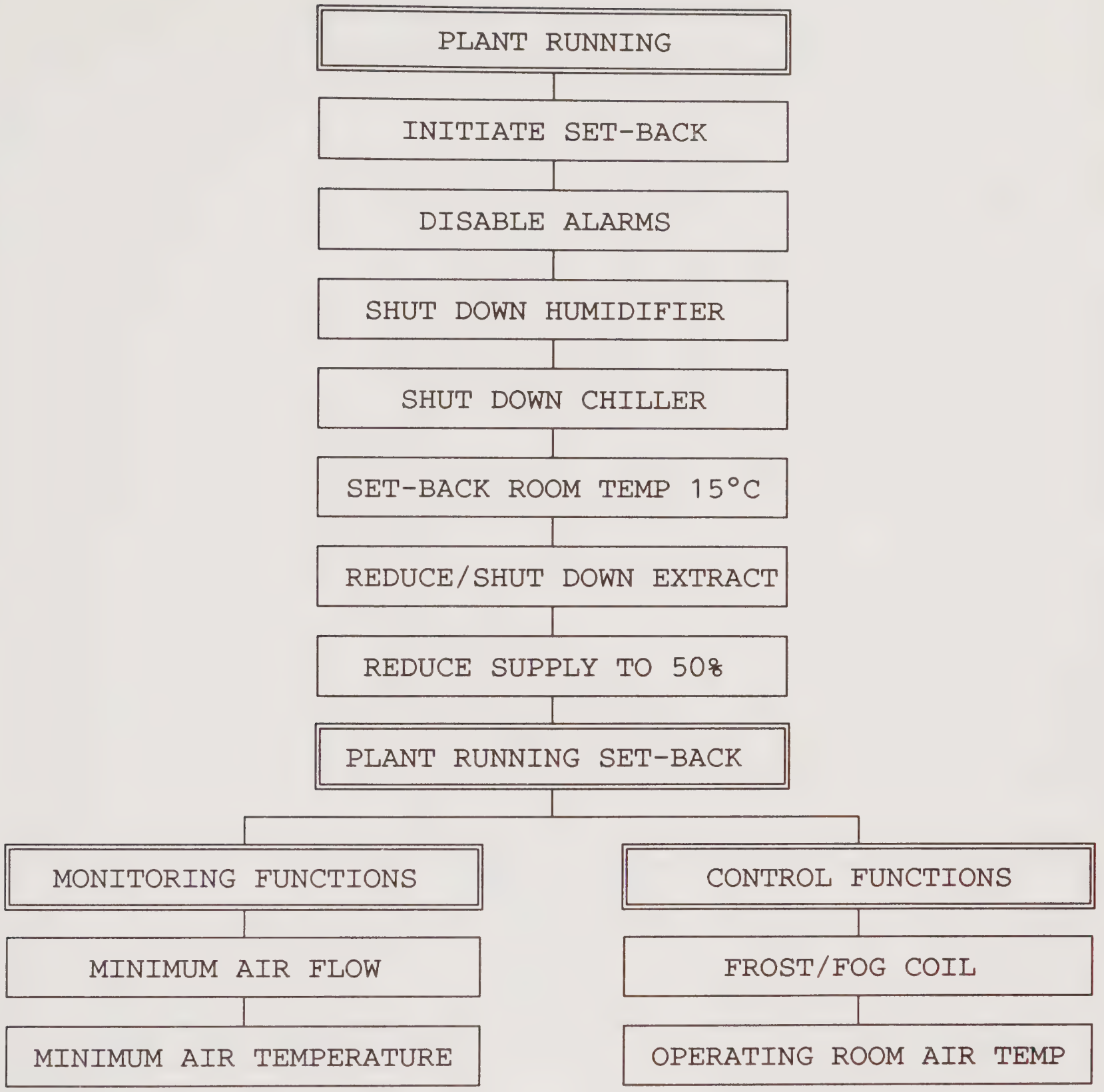


Table 5.3 Plant control algorithm – set-back sequence

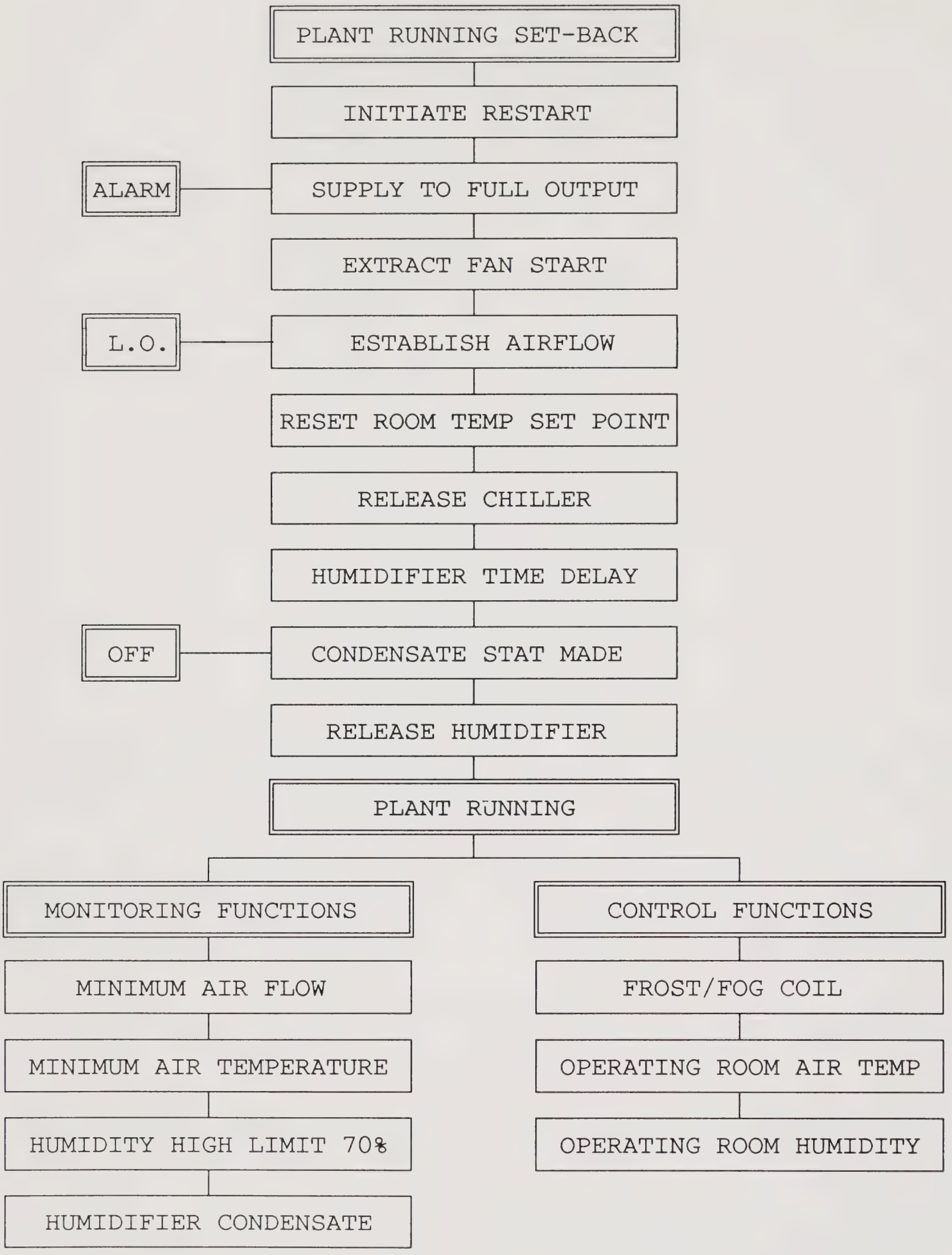


Table 5.4 Plant control algorithm – restart from set-back

6.0 Special ventilation systems

Operating departments

Special requirements

6.1 The supply of air to an operating room has four main functions:

a. to control the temperature and humidity of the space;

b. to assist the removal of and dilute waste anaesthetic gases;

c. to dilute airborne bacterial contamination;

d. to control air movement within the suite such that the transfer of airborne bacteria from less clean to cleaner areas is minimised.

6.2 Functions (a), (b) and (c) are important and must be achieved in full, but it is not essential to achieve perfect air movement control (d), provided that bacterial dilution is adequate.

6.3 Terminal or HEPA filters are not generally required.

6.4 Because of the complexities of controlling air movement patterns, much design effort will be required for this aspect. It is important that the design makes the best possible use of the air available, as excessive supply air flows for the control of air movement should not be used. The maximum air supplied to the operating room should be 1.0 m^3/sec; and this air should be distributed evenly within the space, usually via ceiling diffusers.

6.5 The detailed considerations upon which the supply air flow rate is based are as follows.

Temperature and humidity control

6.6 Supply flow rates to achieve the required room conditions, are calculated conventionally, taking account of all heat and moisture gains and losses, and of maximum permissible temperature differences between the room and supply air.

6.7 Temperature differences of up to 10 K for winter heating and 7 K for summer cooling must not be exceeded.

Removal and dilution of waste anaesthetic gases

6.8 Waste anaesthetic gas must be contained and removed by a suitable gas scavenging system. Some leakage from the anaesthetic equipment and the patient's breathing circuit will occur with all systems, during connection and disconnection; and from the interface with the patient. The air movement scheme should ensure that this leakage is diluted and removed from the theatre suite.

6.9 Air extracted from operating suites should not be recirculated, as it may contain these contaminants; however, an energy recovery system should be fitted in the extract in order to reduce the plant energy consumption.

6.10 It is acceptable for the humidity to swing uncontrolled between 40% and 60% saturation. In the unlikely event of flammable anaesthetic gases being used, a minimum of 50% humidity must be maintained within the operating room. The set point for the humidity control would therefore be set at 55% ±5%.

Dilution of airborne bacterial contaminants

6.11 Supply flow rates for the main rooms of the operating suite are given in Table 6.6. For the other areas where room sizes and activities vary from site to site, air change rates are given in Table 6.1. These figures have been found to give sufficient dilution of airborne bacterial contaminants, provided the mixing of room air is reasonably uniform.

Air movement control

6.12 The design of the system should seek to minimise the movement of contaminated air from less clean to cleaner areas. Transfer grilles or suitably dimensioned door undercuts enable air to pass in either direction between rooms of equal class and pressure. Pressure relief dampers and pressure stabilisers operate in one direction only, allow excess air to be directed to the area desired, and assist in maintaining room pressure differentials.

If it is decided that no flammable anaesthetic gases are to be used, neither this nor the antistatic floor need be provided. In this case, a notice that the theatre suite is not suitable for the use of flammable anaesthetic gases must be prominently fixed at the entrance.

Table 6.1 Hierarchy of cleanliness and recommended air-flow rates for dilution of airborne bacterial contaminants

Class	Room	Nominal pressure Pa (A)	Air flow rate for bacterial contaminant dilution	
			Flow in or supply m^3/s	Flow out or extract m^3/s
Sterile	Preparation room			
	(a) lay-up	35	See Table 6.5 for recommended schemes and specific values	
	(b) sterile pack store	25±5		
	Operating room	25		
	Scrub bay/(B)	25		
Clean	Central sterile pack store	14	0.10	–
	Anaesthetic room	14	0.15	0.15
	Scrub room	14	–	0.10
Transitional	Recovery room	3	15 AC/hr(C)	15 AC/hr(C)
	Clean corridor	3	(D)	7 AC/hr
	General access corridor	3	(D)	7 AC/hr
	Changing rooms	3	7 AC/hr	7 AC/hr
	Plaster room	3	7 AC/hr	7 AC/hr
Dirty	Disposal corridor	0	–	(E)
	Disposal room	–5 or 0	–	0.10

Notes:

A. Nominal room pressures are given to facilitate setting up of pressure relief dampers, the calculation process, and the sizing of transfer devices. The resultant pressures are not critical provided the desired air movement is achieved.

B. An open or semi-open bay is considered to be part of the operating room, and provided air movement is satisfactory, no specific extract is required.

C. 15 AC/hr is considered necessary for the control of anaesthetic gas pollution.

D. Supply air flow rate necessary to make up 7 AC/hr after taking into account secondary air from cleaner areas.

E. No dilution requirement. Temperature control requirements only.

Maintenance of room pressures

6.13 When considering the overall air-flow movement, careful thought needs to be given to the operation of the ventilation system, to limit smoke spread in the event of a fire. However, this is a highly staffed department with a low fire risk/load status and these factors need to be recognised when developing the fire strategy.

Table 6.2 Typical pressures in an operating suite when a given door is open

Door open between	Resultant pressure in these rooms	Effect on other rooms	
		Room	Pressure (Pa)
Operating room and corridor or Scrub bay and corridor	3 Pa	Anaesthetic Preparation – lay up Disposal Preparation – sterile pack store	3 18 –12 8
Operating room and anaesthetic room (or other series room with double doors)	17 Pa	Preparation – lay up Disposal Preparation – sterile pack store	30 –9 22
Operating room and disposal room or Operating room and preparation room	25 Pa	No change	
Anaesthetic room and corridor (or other series room with double doors)	3 Pa	Preparation – lay up Disposal Operating room Preparation room – sterile pack store	30 –9 17 22
Preparation room – corridor Disposal room – corridor	3 Pa	No change	
Disposal room – outer corridor	0	No change	

6.14 Air should flow from the cleaner to the less clean areas as shown in Table 6.1. This is fairly easy to achieve by creating room pressure differentials if the doors are closed, but once a door is open, the pressure differentials are much more difficult to maintain (see Table 6.2). This difficulty is caused by the following:

a. when a person passes through a doorway, both the passage of the person and the movement of the door flap cause a transfer of air between the areas separated by the door;

b. when a door is left open there is a transfer of air between the two areas separated by the doorway. This is caused by air turbulence, but is greatly increased by any temperature differential between the areas (a 1.4 m wide doorway may allow the transfer of 0.19 m^3/s of air in each direction when there is no temperature difference, but when the temperature differential increases to say 2 K, the volume transferred may increase to 0.24 m^3/s).

6.15 To minimise the airflow between areas of different orders of cleanliness, air movement control schemes must be designed to ensure that excess air flows through the doorway from the clean to the less clean area.

6.16 It is not possible to design an air movement scheme, within the restraints of the amount of air available, that will protect the operating room when two

doors are simultaneously opened. The design process used here considers that each door is opened in turn and ensures that the direction and rate of air flow through any open doorway is sufficient to prevent any serious back-flow of air to a cleaner area.

Table 6.3 Recommended air flow rates in m^3/s through a doorway between rooms of different cleanliness to control cross-contamination

Room class		Dirty	Transitional	Clean	Sterile
Sterile	Hatch	0.3	0.24	0.18	
	Single door	0.47	0.39	0.28	0 or 0.28 (C)
	Double door	0.95	0.75	0.57	o or 0.57 (C)
Clean	Single door	0.39	0.28	0 or 0.28 (C)	
	Double door	0.75	0.57	0 or 0.57 (C)	
Transitional	Single door	0.28	0 or 0.28 (C)		
	Double door	0.57	0 or 0.57 (C)		
Dirty	Single door	0	Open single door = 0.80 m x 2.01 m high		
	Double door	0	Open double door = 1.80 m x 2.01 m high		

Notes:

A. The degree of protection required at an open doorway between rooms is dependent upon the degree of difference in cleanliness between them.

B. Flow rate required between rooms within the same class tends to zero as class reduces.

C. If two rooms are of equal cleanliness, no flow is required (in practice there will be an interchange in either direction) and the design of the air movement will assume zero air flow. In certain cases, however, interchange is not permitted and a protection air flow of 0.28 is assumed in the design, for example in the case of a preparation room used as a "lay up".

6.17 The recommended air flow rates to achieve this are given in Table 6.3. Provided that the dilution criteria in Table 6.1 are met, the occasional small back-flows created (when two doors are opened simultaneously; or when there is a high temperature difference across an open door) will have little effect on the overall air cleanliness of the affected room.

Notes on the layout of operating suites

6.18 The following general points should be taken into consideration during the design of operating suites:

a. number of exits – the fewer the number of rooms (and therefore doorways) leading from the operating room the better, as traffic is reduced and less complicated air movement control schemes are required;

b. scrub and hand-wash facilities – these may be a part of the operating room, often in a bay.

   Should a separate room be required for the scrub area, a door between the scrub-up room and the operating room is an inconvenience to scrubbed staff, and could be replaced by an opening. This opening should be larger than a normal single doorway;

c. lay-up room – if it is intended to "lay up" instruments in the operating room, the preparation room is then used simply as a sterile pack store. The nominal room pressure can therefore be the same as that of the operating room and the air flow between the two rooms in either direction. Air supplied to the preparation room may be directed into the operating room, thus reducing the required quantity of air supplied

directly to the operating room, and consequently the total volume required for the necessary air movement control;

d. preparation room – when the preparation room is used as an instrument "lay-up" room in the traditional way, it should be regarded as being of greater cleanliness than the operating room, and the design should minimise the transfer of air from the operating room to the preparation room;

e. dirty corridor – if materials to be disposed of are placed in impervious material for transportation, it is not necessary to have a separate corridor for this purpose.

Standard air movement control schemes

6.19 Air movement control schemes have been developed for several possible operating suite layouts as follows:

Plan 1a – single corridor with sterile pack store;

1b – single corridor with lay-up;

2a – linked corridor with sterile pack store;

2b – linked corridor with lay-up;

3 – linked corridor with external scrub and sterile pack store;

4 – Nucleus plan two corridors, with sterile pack store and disposal hatch;

5a – two corridor with sterile pack store;

5b – two corridor with lay-up.

6.20 These appear in diagrammatic form in Figure 6.1, which shows the relationships of rooms and the various doors and transfer devices between them, and should not be regarded as architectural layouts. The schemes have been developed using the calculation procedure described in Appendix 1 of this HTM. Important features of the solutions are:

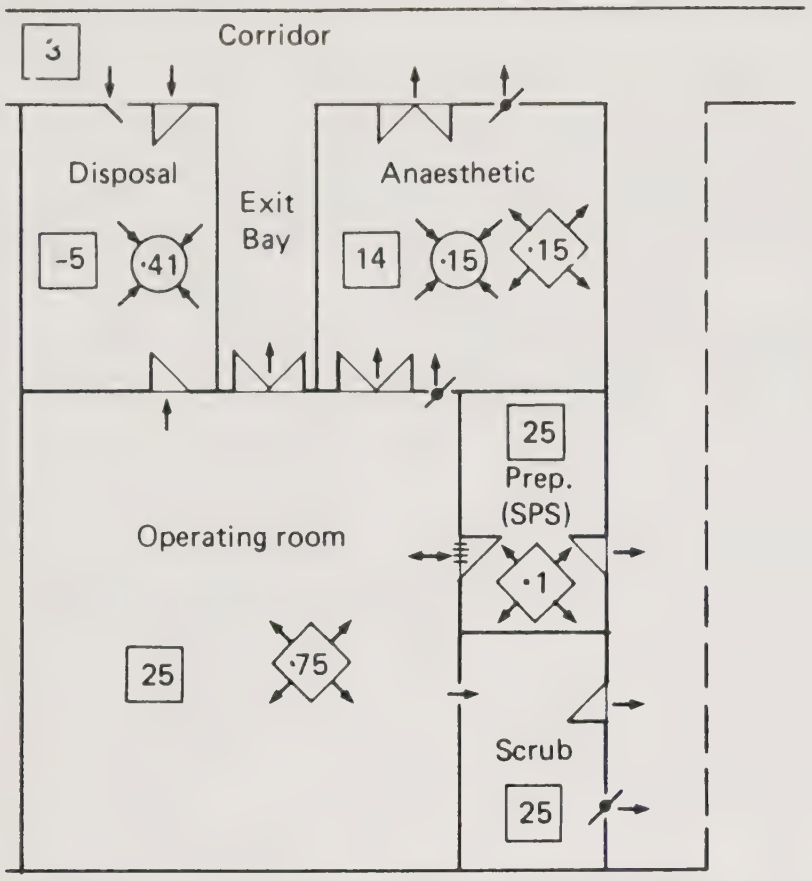
a. zonal trimmer heaters – a trimmer heater battery is advocated when calculations indicate that the temperature differential between rooms may be greater than 2 K. Generally this will only be the case in the preparation room;

b. the preparation room (sterile pack store)/operating room interface – these rooms are deemed to be of equal cleanliness, and thus a transfer grille is required between these rooms;

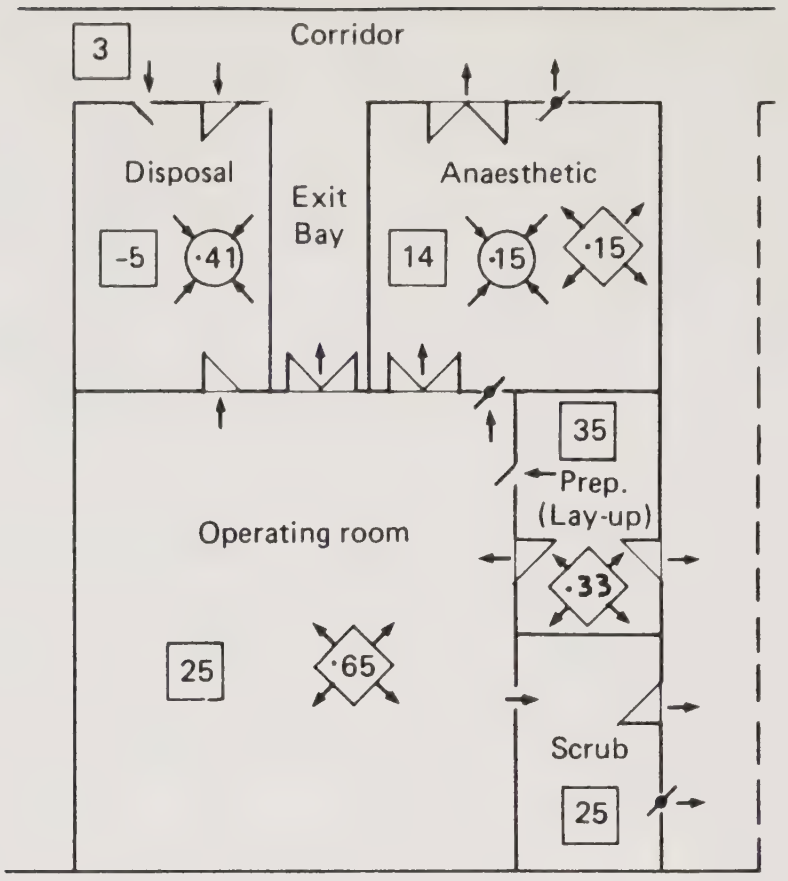
c. preparation (lay-up)/disposal room interface – pressure relief dampers are recommended here to provide an airpath when doors are closed, while preventing back-flow when a door is opened elsewhere;

d. operating room/anaesthetic room interface – pressure stabilisers, or in some cases carefully sized transfer grilles or door undercuts, are recommended here, and between the anaesthetic room and corridor, and between the operating room and corridor;

e. operating room/scrub room interface – an opening is provided between these rooms. The flow of air through the opening provides protection, and gives bacterial dilution within the scrub room; the air is then exhausted to the corridor via a pressure stabiliser.



Plan 1a
Single corridor with sterile pack store



Plan 1b
Single corridor with lay-up

KEY:

Supply m^3/s

Extract m^3/s

Nominal pressure Pa

Desired airflow

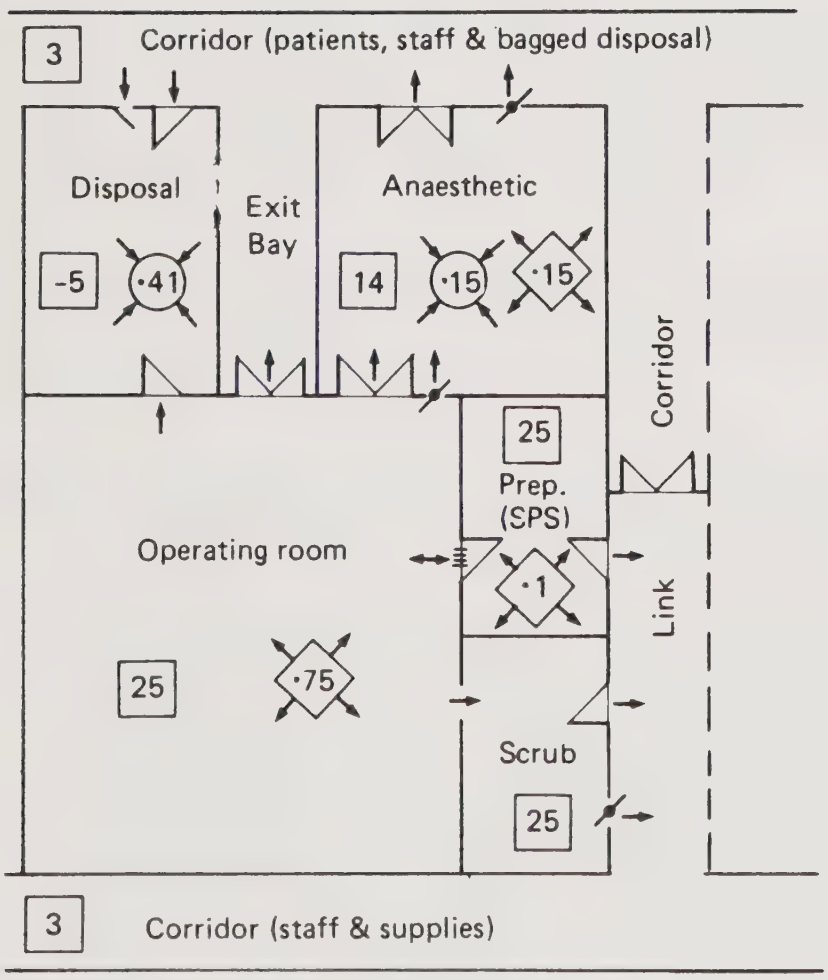
Door (double)

Door (single)

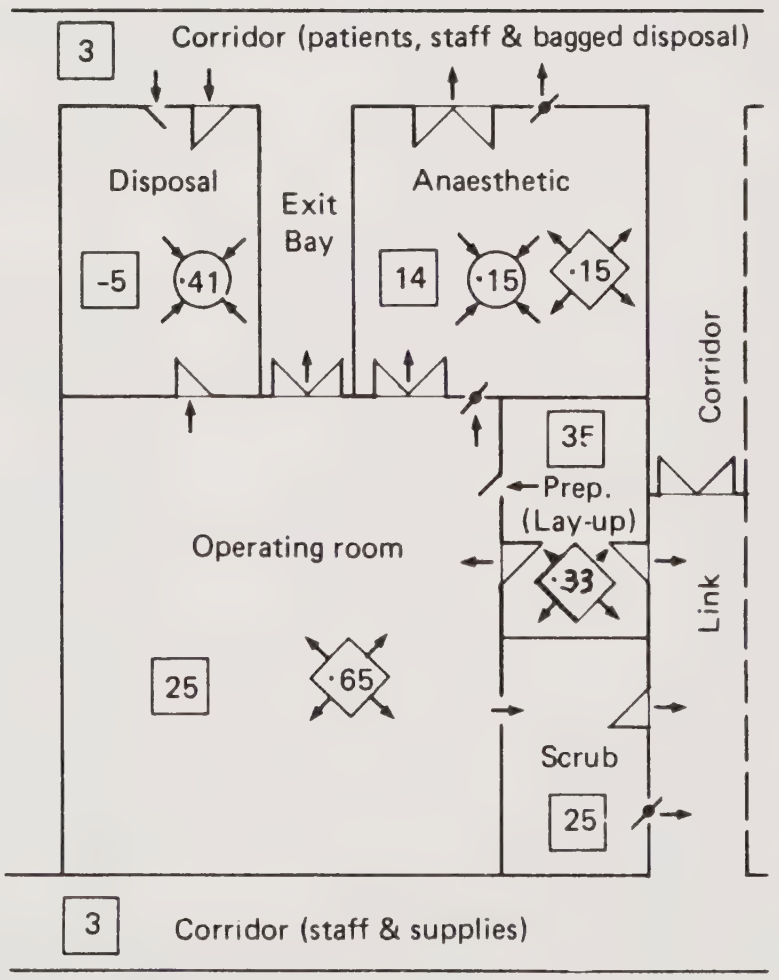
Door mounted transfer grille

Pressure relief damper

Pressure stabilizer

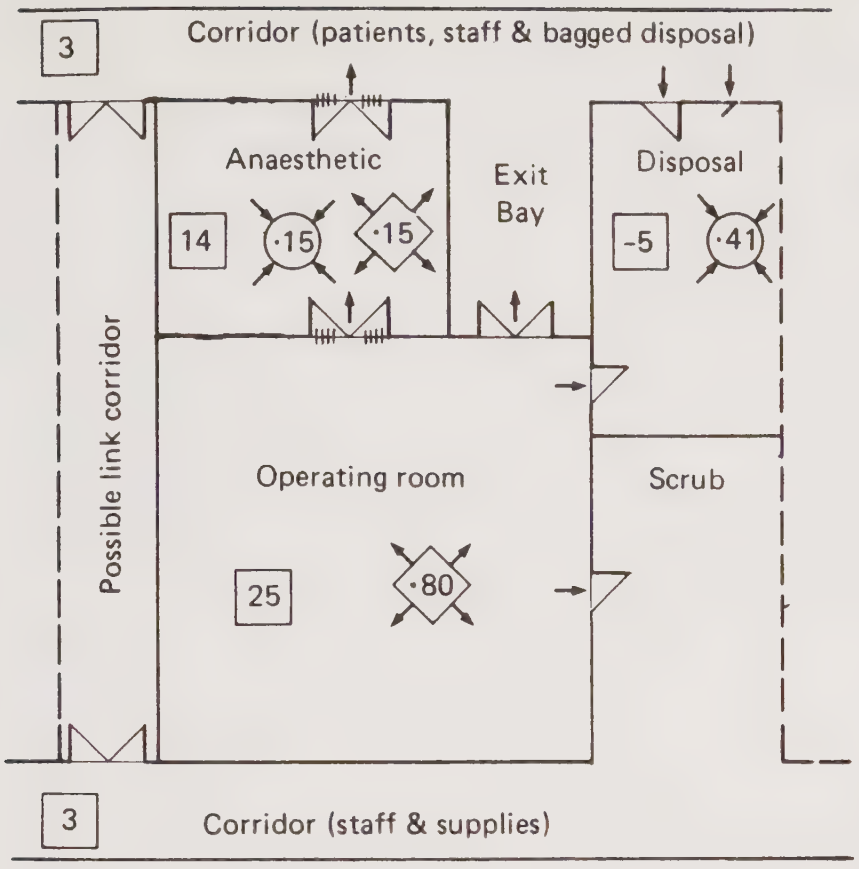


Plan 2a
Linked corridor with sterile pack store

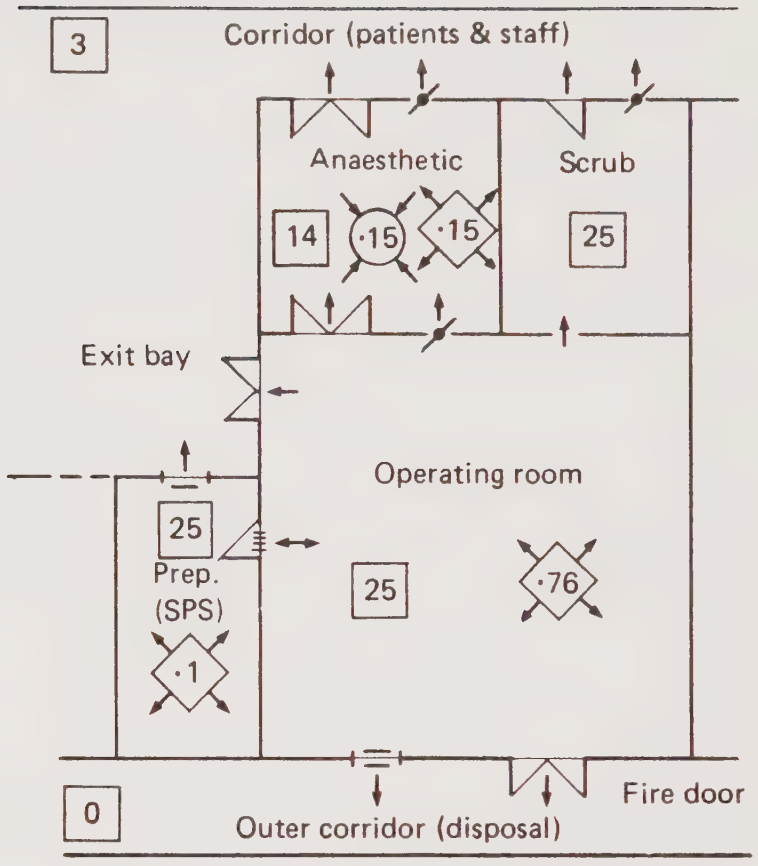


Plan 2b
Linked corridor with lay-up

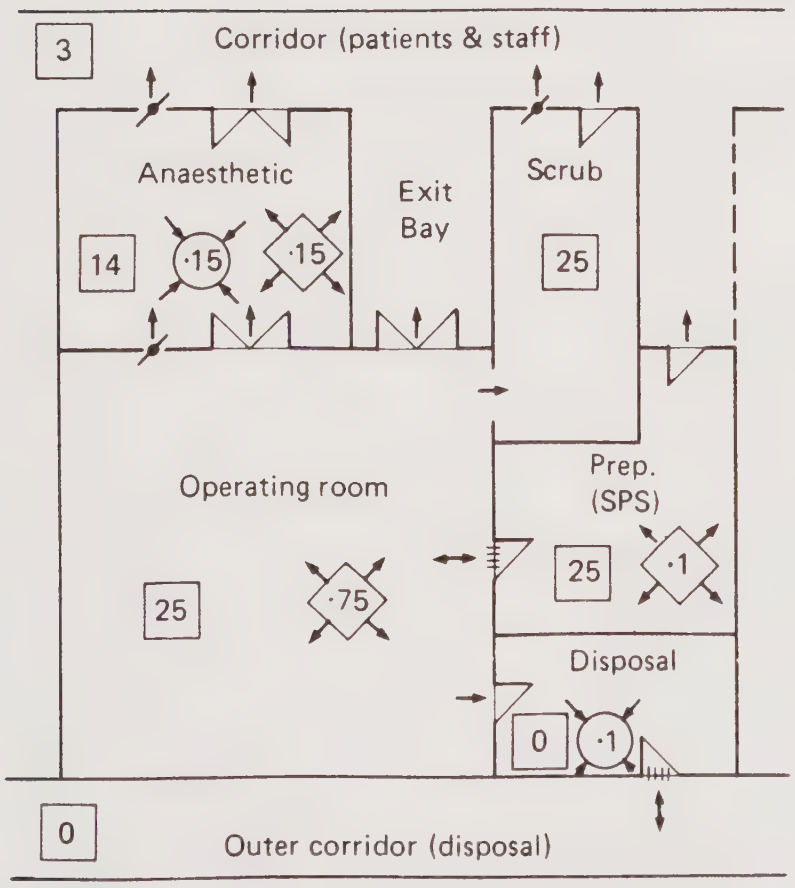
Figure 6.1 (a) Eight suggested air movement control systems



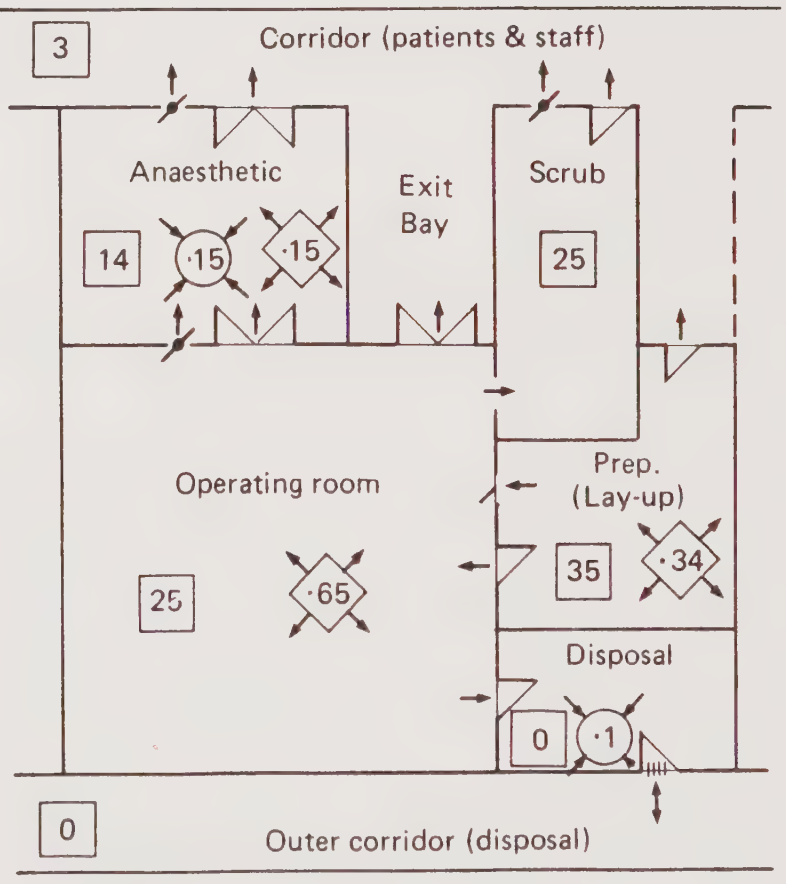
Plan 3
Linked corridor with external scrub and remote sterile pack store



Plan 4
Two corridor sterile pack store with disposal hatch



Plan 5a
Conventional two corridor with sterile pack store



Plan 5b
Conventional two corridor with lay-up

Figure 6.1 (b)

No mechanical supply or extract ventilation is provided in the scrub room, and thus when a door is opened elsewhere in the suite, the stabiliser will close, allowing the air to be re-directed to help protect the doorway.

6.21 Any other scheme may be used and the standard solutions applied, if the following conditions are met:

a. room layouts in air network terms are as shown in the plans in Figure 6.1;

b. door gaps approximate to those given in Component Data Base (4 mm along bottom, 3 mm along top and sides, 2 mm between double leaves), see Table 6.4;

c. heat gains are similar to those given in Table 6.5;

d. a trimmer battery is installed in the air supply system to the preparation room;

e. leakage through the structure is kept to a minimum.

A complete specification is given in Table 6.6.

Table 6.4 Leakage flows in m^3/s through closed door gaps

Type	Pressure difference – Pa						
	5	10	15	20	25	30	40
Single door (CDB Size 2.4.3.2.6.)	.03	.05	.06	.06	.07	.07	.08
Double door (CDB)	.04	.08	.10	.11	.12	.13	.14
High permanent length of 3 mm gap	.004	.008	.010	.011	.012	.012	.013

Note: CDB = Component Data Base - see paragraph 6.21.

6.22 It is recommended that every effort should be made to adopt one of the schemes described earlier. Provided it is possible to comply with the specifications given in Table 6.6, the entire design may adopted; otherwise, the manual design procedure should be followed.

Air distribution within rooms

6.23 The method of introducing air into the operating room is of little bacteriological significance at the recommended rates of flow. The velocity working zone should be between 0.1 m/s and 0.3 m/s and diffuser equipment should be selected to avoid "dumping".

6.24 In the operating room, the air terminals must be at high level, and should all be adjustable for rate of flow as well as being easily cleaned and silent in operation. Supply terminals will require means of directional adjustment.

6.25 Large supply diffusers, for example "ultra-clean" style diffusers, are particularly prone to buoyancy effects as a result of temperature difference (see paragraphs 6.48–6.83). Unless the manufacturer of a proprietary system of this type is able to provide type test data of the performance envelope, the installation of these devices is not recommended.

Automatic control

6.26 Each operating room should have a sampling extract duct for the air-conditioning control sensors. This should be positioned at normal working height (1.8 m above fixed floor level (AFFL)) and be accessible for cleaning and removal of fluff and lint.

Table 6.5 Heat gains and losses assumed in standard solutions

Room	Item	Typical heat gains (watts) Summer (S)	Winter (W)
Operating	8 people at 150 w/p (a)	1,200	1,200
	Lights – general	750	750
	Lights – operating	1,000	1,000
	Fabric	250	–750
	Equipment (b)	1,000	1,000
	Nett gain	4,200	3,200
Preparation	1 person at 150 w/p	150	150
	Lights – general	140	140
	Fabric	60	–160
	Equipment	0	0
	Nett gain	350	130
Scrub	0 people (during operation)	0	0
	Lights – general	180	180
	Fabric	70	–140
	Equipment	0	0
	Nett gain	250	40
Anaesthetic	3 people at 150 w/p	450	450
	Lights – general	300	300
	Fabric	150	–280
	Equipment	100	100
	Nett gain	1,000	570
Disposal	0 people (during operation)	0	0
	Lights – general	150	150
	Fabric	50	–150
	Equipment	0	0
	Nett gain	200	0

Notes:

a. typical maximum;
b. includes full patient monitoring, video monitors, diathermy etc. To be taken into account for selecting the cooling plant.

6.27 This duct should run from the sampling point and either connect into the general extract ductwork system, or be provided with its own fan, built into the operating theatre surgeon's panel.

6.28 Where one supply and extract plant serves two operating rooms, the sensors should be located in the common extract duct at a point where there is a representative sample of air from both rooms.

6.29 The individual control sensors should be removable to prevent damage during cleaning. Wall-mounted sensors, thermostats and humidistats are not recommended.

6.30 Controls should be provided in the air-handling plantroom to enable operating department ventilation plants to be closed down when the operating suites are unoccupied.

6.31 When in the "off" mode, the control system should ensure that the ventilation plant is automatically reinstated if the space temperature falls below 15°C. Theatre ventilation plant control and its status indication for run and stop should also be located at the staff control base.

Table 6.6 Air movement control specification for standard plans – (a) supply and extract flow rates

Item	Specification			Plan							
	Room	Nominal pressure (pa)	Flow rate (m^3/s)	1a	1b	2a	2b	3	4	5a	5b
Air Supply (S) and Extract (E) flow rates and nominal room pressures	Operating room (OR)	25	0.75 S	*		*				*	
			0.65 S		*		*				*
			0.80 S					*			
			0.76 S						*		
	Anaesthetic room (AN)	14	0.15 S	*	*	*	*	*	*	*	*
			0.15 E	*	*	*	*	*	*	*	*
	Sterile pack store (SPS)	25±5	0.10S	*		*			*	*	
	Instrument lay-up (LU)	35	0.34 S		*		*				*
	Scrub bay (SC)	25	0.00 S	*	*	*	*	*	*	*	*
			0.00E								
	Disposal (DI)	–5	0.41E	*	*	*	*	*			
		0±5	0.10E							*	*
	Clean corridor (CC)	3	7 ac/h	*	*	*	*	*	*	*	*
	Outer corridor (DC)	0							*	*	*
	Total supply to the suite		1.00 m^3/s	*		*				*	
			1.14		*		*				*
			0.95					*			
			1.01						*		

Notes: S – Supply
E – Extract
Ac/hr – Air changes per hour

6.32 The theatre control panel should also include plant status indication; temperature and humidity indicating gauges; and means of adjusting the setpoint for temperature and humidity. The panel should also include the air sampling terminal.

6.33 The humidity within the operating department should be kept within the range 40% to 60%. Provision should be made for raising the minimum level to 50% in the unlikely event that flammable anaesthetics are to be used. The humidifier should be selected to humidify to 50% saturation at 20°C during the design winter outside conditions, and the cooling coil should be able to remove sufficient moisture so that 60% saturation at 20°C is not exceeded during the design summer outside conditions.

Plant arrangement

6.34 Cost analysis has shown that there can be economic advantages in serving each operating suite with independent supply and extract plant. There are also operating and thermodynamic advantages to be gained from this arrangement.

Table 6.6 Air movement control specification for standard plans – (b) transfer devices

Item	Specification			Plan							
	Location and flow direction	Flow rate (m^3/s)	Pressure (Pa)	1a	1b	2a	2b	3	4	5a	5b
Transfer grilles (Door mounted) or Door undercut	OR → AN & AN → CC	0.53 (c)	14					*			
	OR ↔ SPS	0.23	22	*		*				*	
		0.03	5						*		
	DC ↔ DI	0.40	25							*	*
Pressure relief dampers (Wall mounted)	LU → OR	0.22	10		*		*				*
	CC → DI	0.29	8	*	*	*	*	*			
	SC → CC	0.22	22	*	*	*	*		*	*	*
Pressure stabilisers (wall mounted)	OR → AN & AN → CC	0.47	14 (a)	*	*	*	*	d	*	*	*
		0.22	22	*		*			*	*	
	OR → CC (B)	0.35	22		*		*				*
		0.45	22					*			

Notes:

a. If excess OR air is to be routed via AN, the pressure setting of AN stabilisers is to be 11 Pa, and OR → CC stabiliser is then not required.

b For use when excess OR air is to be passed directly to CC.

c. Plan 3 only; use transfer grilles only when excess OR air is to be routed via AN (see note (d)).

d. Plan 3 only; use pressure stabilisers only when excess OR air is to be passed directly to CC (see notes (b) and (c)).

Table 6.6 Air movement control specification for standard plans – (c) open door air flows

Item	Specification			Plan							
	Location and flow direction	Size	Flow rate (m^3/s)	1a	1b	2a	2b	3	4	5a	5b
	LU → OR	Single	0.28		*		*				*
	OR ↔ SPS	Single	0	*		*			*	*	
Design flow rates through open doors.	OR → DI	Single	0.47	*	*	*	*				
	OR → DI	Single	0.60							*	*
	OR → SC	(a)	0.28	*	*	*	*		*	*	*
	OR → CC	Single	0.39					*			
Note: In many cases the actual flow will be greater than this.	OR → CC	Double	0.75	*	*	*	*	*	*	*	*
	OR → AN	Double	0.57	*	*	*	*	*	*	*	*
	AN → CC	Double	0.57	*	*	*	*	*	*	*	*
	LU → CC	Single	0.39		*		*				*
	SPS → CC	Single	0.39	*		*				*	
	SC → CC	Single	0.39	*	*	*	*		*	*	*
	DC ↔ DI	Single	0							*	*
	CC → DI	Single	0.28	*	*	*	*				
	OR → DC	Double	0 (b)						*		
	OR → DC	Hatch	0 (c)						*		
	SPS → CC	Hatch	0.20						*		
Trimmer heater	LU supply				*		*				*
	SPS supply			*		*			*	*	

Notes:

a. Single opening - no door

b. = Fire door

c. = Air lock

6.35 As a general rule, if a theatre is out of use, but having to be supplied with air from a common plant for more than 25% of the time, a separate plant will be preferred. In any event, it is recommended that a plant or common plant components be limited to supplying two operating suites.

Ventilation of ancillary areas

General

6.36 In order to maintain airflow patterns in the operating suite, it is recommended that the whole department should be mechanically ventilated, and that the plant be sized to cope with all heat losses, thereby making separate radiator or convector systems unnecessary. The grilles and diffusers should be located to eliminate condensation on windows and provide even air distribution. The use of ceiling heating and embedded heating panels is not recommended.

Ventilation requirements

6.37 Table 6.6(a) gives guidance on the operating department areas in descending order of cleanliness, and this should be considered in the overall design of the department ventilation systems. The specified flow rates of air through doors given in Table 6.6(c) for the operating suite are not necessary for other areas of the department, however, the airflow directions must be maintained from the clean to the less clean areas.

6.38 All windows in the department should be double-glazed and hermetically sealed in order to ensure that the desired air-flow pattern is maintained under all external environmental conditions, and to avoid infestation.

Systems design

6.39 The design of the ventilation system for the ancillary rooms depends on the overall configuration of the department. The ancillary room plants may need to be interlocked to the theatre suite plant so that reverse air-flow patterns do not occur.

6.40 Generally, the most satisfactory solution is to have a number of plants. Spare motors should be provided, but apart from this, no provision for standby plant can normally be justified.

6.41 If a standby plant is required, it must be provided with a gas-tight damper at its junction with the supply distribution duct, so that no back-flow can occur. Standby plants can become sources of contamination if warm moist air is allowed to stand in them. Their design must ensure that this cannot happen.

6.42 Dual-duct high velocity systems have advantages, but are noisy, costly and may give rise to unacceptable values of humidity; thus, single-duct, low velocity/pressure systems are preferred.

6.43 Extract grilles should be sited and balanced to promote air movement along the clean and access corridors towards the reception/transfer areas. This should not affect the air distribution in the operating suite.

Sterilizing and disinfecting unit

6.44 Because of high heat gains within this department, it is possible that ventilation in excess of 7 air changes per hour may be necessary. Sterilizers,

steam and condensate piping, valves etc. must be carefully and efficiently lagged and the plant space adequately ventilated.

Reception

6.45 The aim in these areas is to provide comfortable conditions having regard to the movement control requirements of the department as a whole. The number of air changes will depend on the design, but 7 per hour should give acceptable conditions.

Recovery

6.46 The air change rate in the recovery room will be rather higher than that needed merely to provide clean, comfortable conditions, as it is necessary to control the level of anaesthetic gas pollution; 15 air changes are recommended, with a balanced air flow.

6.47 Where possible, the supply air terminals should be ceiling-mounted above the recovery bed positions so that anaesthetic gas exhaled by recovering patients will be immediately diluted.

Ultra-clean ventilation systems

Special requirements

6.48 Ultra-clean ventilation (UCV) systems installed in operating rooms can reduce the joint sepsis rate after total joint replacement surgery to approximately half that found in a conventionally-ventilated operating room. Clothing designed to reduce airborne bacteria dispersion (total body exhaust gowns) when used in UCV systems, was shown to reduce the sepsis rate by half again. The bacteria counts at the wound site associated with these results are approximately $10/m^3$ and $1/m^3$ respectively. A minimum standard for the UCV has been suggested where the average count at the wound should not exceed 10 bacteria carrying particles/m^3 (BCP/m^3). However, it is also suggested that to ensure minimal or no contamination of the wound from the air, an airborne concentration of no more than 1 BCP/m^3 would be required.

6.49 Investigations have shown that different designs of UCV systems give different airborne bacteriological concentrations.

6.50 Many design issues such as the merits of vertical or horizontal flow systems, the use of partial or full walls, the choice of special operating room etc are not discussed in depth. Systems designed and commissioned in accordance with this guidance can provide a significant benefit to patients.

Design considerations

6.51 The design philosophy of a conventionally ventilated operating suite is based on the need to dilute contaminants and control both the condition and movement of air in the suite.

6.52 The general objective of an ultra-clean ventilation (UCV) system is to provide clean filtered air in the zone in which the operation is to be performed; and sterile instruments and drapes are exposed. This is achieved by means of a uni-directional discharge of air from an air filter bank or diffuser over the sterile field of the operation. Generally, vertical flow systems provide a more effective solution than horizontal flow systems.

6.53 Some factors which are important when designing operating departments with conventional ventilation systems are not relevant when an UCV system is to be installed. UCV systems are so efficient in preventing airborne bacteria reaching the sterile zone, and in reducing the bacterial concentrations in the remainder of the operating room, that there is no need for complex air movement control schemes; and except for the preparation room, there is no need for high air supply volumes to adjacent areas.

6.54 There are several factors to be considered when designing a UCV system:

a. convection up-current from the surgical team, the operating lamp and buoyancy effects tend to counter the movement of clean air towards the wound, hence the discharge velocity is critical;

b. the size of the operating zone has to be large enough to encompass the operating site and instruments; consequently, a large area of air diffusion is required (typically 7.8 m^2);

c. the high discharge air velocities and large area of air distribution continue to produce a high discharge air volume, and thus, recirculation of a considerable proportion of this volume is essential to minimise operating costs.

6.55 Because of the size of the uni-directional flow terminal and the large volume of air being moved in a relatively small space, the siting of the return air grilles can cause short-circuiting of the air discharge. Partial walls must be provided to control short-circuiting.

6.56 Return air grilles can be positioned at high level adjacent to the "partial wall", but the partial wall must be not less than one metre from the operating room wall.

6.57 A further factor affecting the air flow pattern is the supply/room air temperature difference. The supply air temperature should not exceed the general room temperature. If the supply air temperature is above room temperature, buoyancy effects reduce the volume of air reaching the operating zone. In such cases only systems with full walls should be used as, if the temperature difference is greater than 1K, it will prevent air reaching the operating site. A full wall is considered to apply to any wall terminating not more than one metre above the finished floor level.

6.58 The term "laminar flow" is generally misused when discussing UCV systems. Commercial systems are available which provide a true laminar flow from the terminal (Reynolds No <2000), but this "laminar flow" will be destroyed due to the disturbance caused by the operating light and personnel. Most systems produce the uni-directional non-laminar flow from the terminal.

6.59 The air movement in the operating room as a whole will ultimately depend on:

a. the discharge velocity, velocity profile;

b. the provision of full or partial walls;

c. the location of the extract grilles;

d. the supply/room air temperature difference.

Operating department design consideration

6.60 A UCV system will usually be designed to provide the air-conditioning to an individual operating suite, and will include primary, secondary and terminal filtration and diffusion of air. Heating, cooling, humidification, attenuation controls and instrumentation to the standards set out for a conventional operating suite will also be included as part of the installation.

6.61 Separate scrub-up and disposal facilities are not necessary for air cleanliness where a UCV system is installed, although operational policy may prefer such a provision. A separate anaesthetic room should however be provided. The preparation room/sterile store can be shared where the workload permits. When a sterile store is provided, laying up in the clean zone is preferable bacteriologically.

6.62 There is no aerobiological reason why two or more UCV systems should not be installed in a common area as long as adequate spacing is provided, but this will require special design considerations and operational discipline.

Selection of UCV system

6.63 The types of UCV systems available are as follows.

Remote plant systems

6.64 In a remote plant system, all the air-conditioning equipment is located outside the operating room, except for the uni-directional air flow terminal, the terminal filter, and the return air grilles/filter (see Figure 6.2).

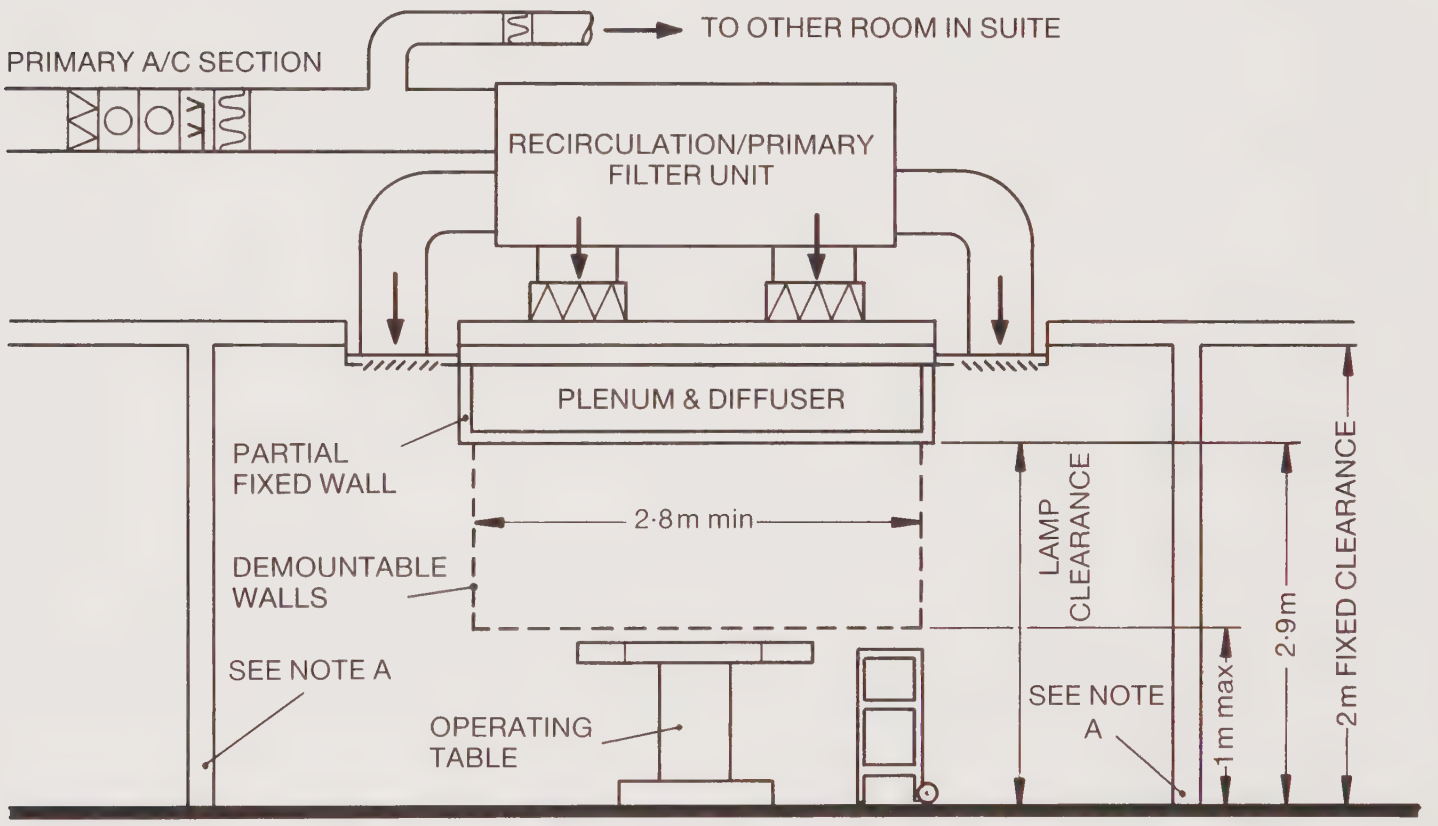


Figure 6.2 Typical remote plant UCV system

Note: Final filters may form part of plenum chamber

Modular systems

6.65 Horizontal flow systems are typically of the modular type, and can be:

a. vertical flow - comprising a recirculating air module containing final filter and terminal.

   Return air filters and fans may be incorporated into a false ceiling to improve headroom.

   These do not include primary "fresh air" conditioning equipment within the module. The module must be connected to the primary air-conditioning system (see Figures 6.3 and 6.4).

b. horizontal or cross flow - comprising a recirculating air module standing vertically to produce a horizontal flow of air; and containing final filter/diffuser, return air filters and fans.

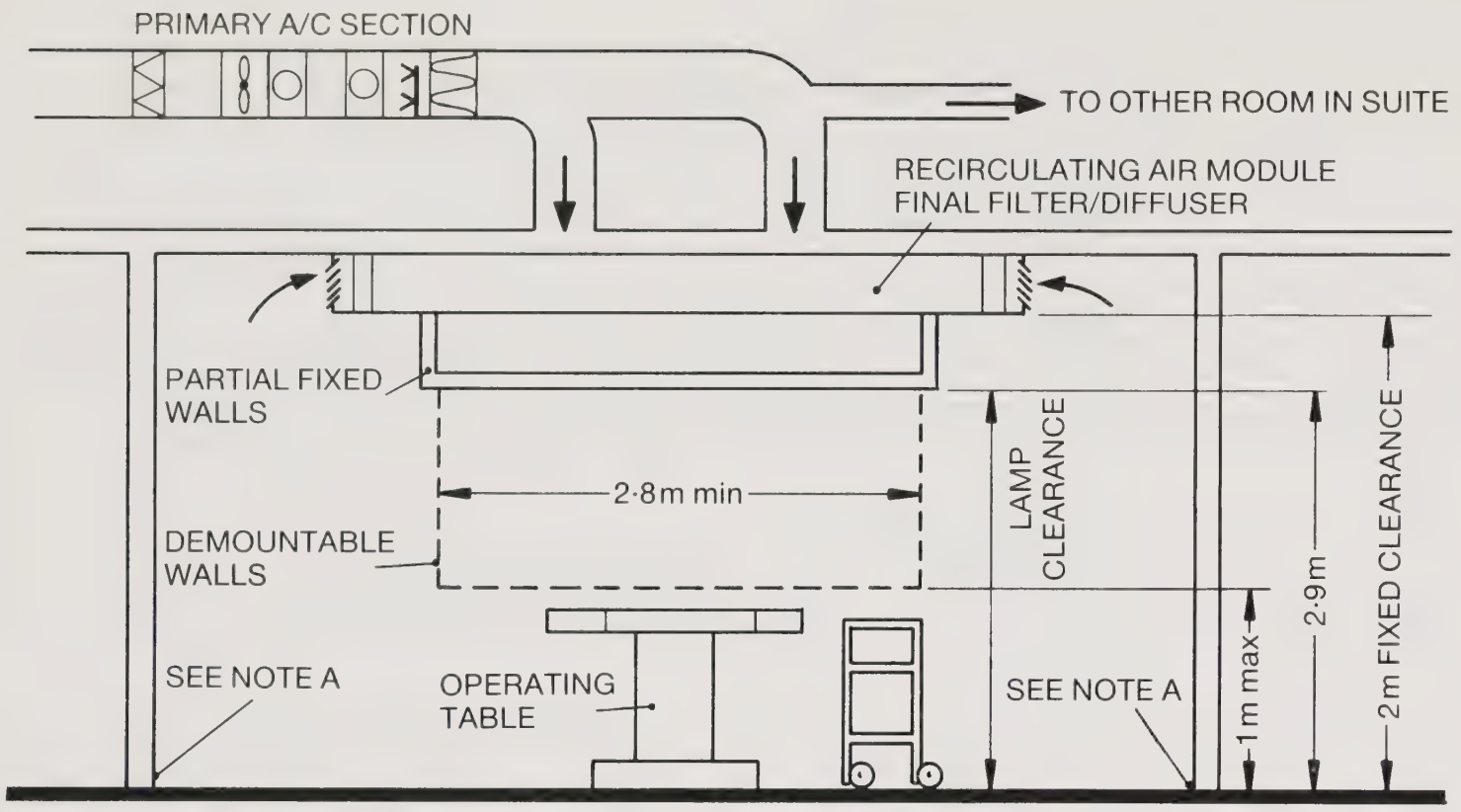


Figure 6.3 Typical commercial modular system

Note: Make-up air volume escapes to peripheral area via doors etc.

The system must have side walls which may fold to facilitate cleaning of the theatre. A deflector at the top of the filter/diffuser will be acceptable as an alternative to a full roof.

Regardless of which of the above systems is preferred, the recirculation fan power may necessitate the inclusion of supplementary cooling coils within the module. These should be designed to the same criteria as the main plant. To avoid problems with the removal of moisture from the cooling battery, it is preferable to effect cooling by means of the primary supply system.

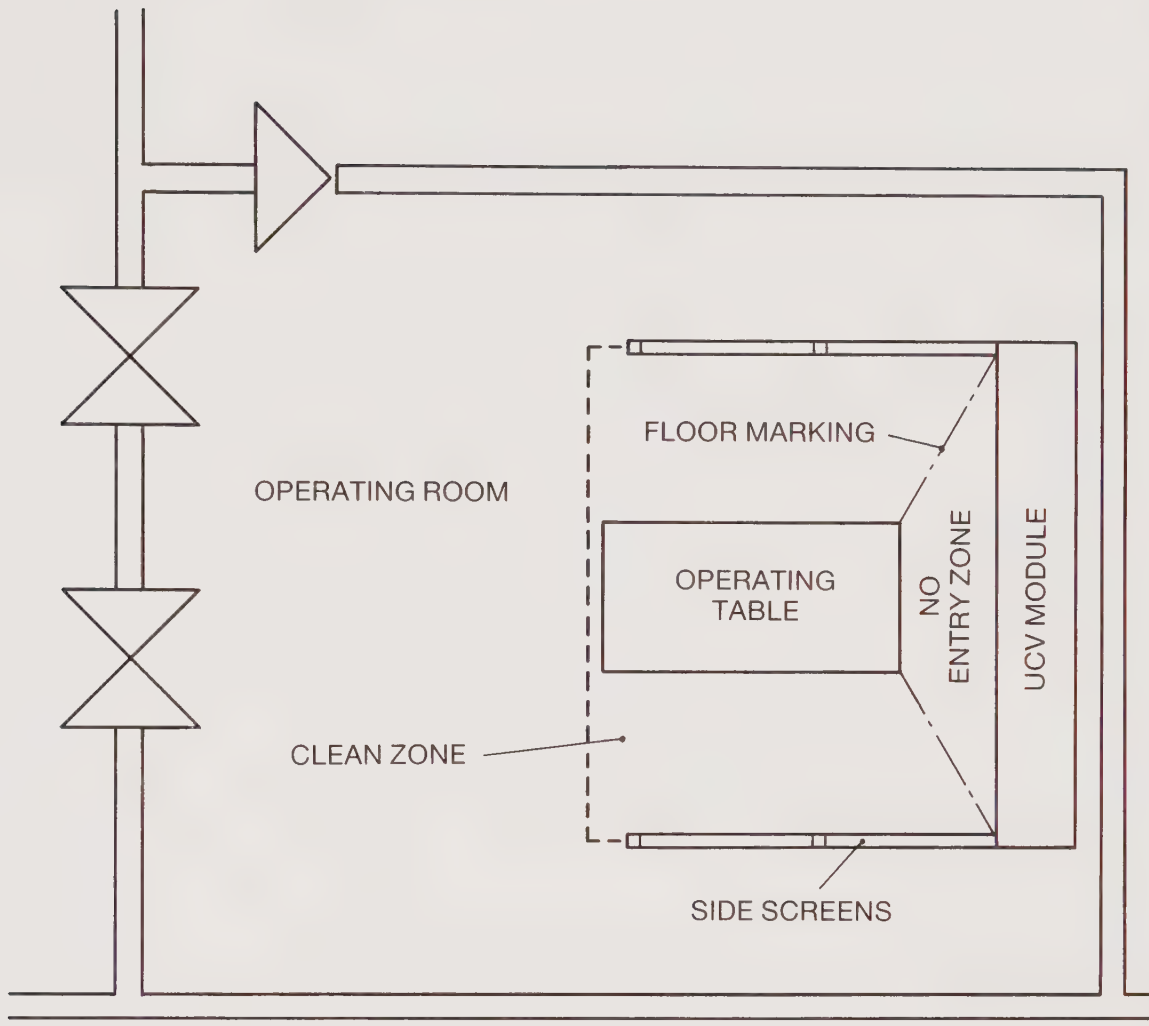
6.66 The number of bacteria at the wound site depends on the operating team, their discipline and the type of UCV system and choice of clothing. Table 6.7 indicates the typical range of values for bacteria carrying particles per cubic metre of air (BCP.m^3) which can be expected at the wound site, and shows the combination of clothing and system selection required. The maximum recommended standard is 10 BCP/m^3. The installed system will be required to meet the performance standard set out in the "Validation and verification" volume of this HTM.

Table 6.7 Typical performance of UCV systems for different types of clothing – BCP counts expressed as an average over a number of operations

Types of clothing	Horizontal flow system with walls	Vertical flow system
Conventional cotton clothing	> 10 BCP/m^3	> 1 : < 10 BCP/m^3
Clothing designed to minimise dispersion of bacteria	> 1 : < 20 BCP/m^3	< 1 BCP/m^3

6.67 Horizontal flow systems have been shown to be three to volume eight times less effective than vertical flow systems, and clothing designed to minimise dispersal of bacteria is up to 20 times more effective than conventional cotton clothing.

6.68 It should be the objective when designing a UCV system to achieve levels of less than 10 BCP/m^3 when conventional cotton clothing is used, so that the use of occlusive clothing or body exhaust systems result in counts of less than 1 BCP/m^3.



PLAN OF TYPICAL HORIZONTAL UCV MODULE

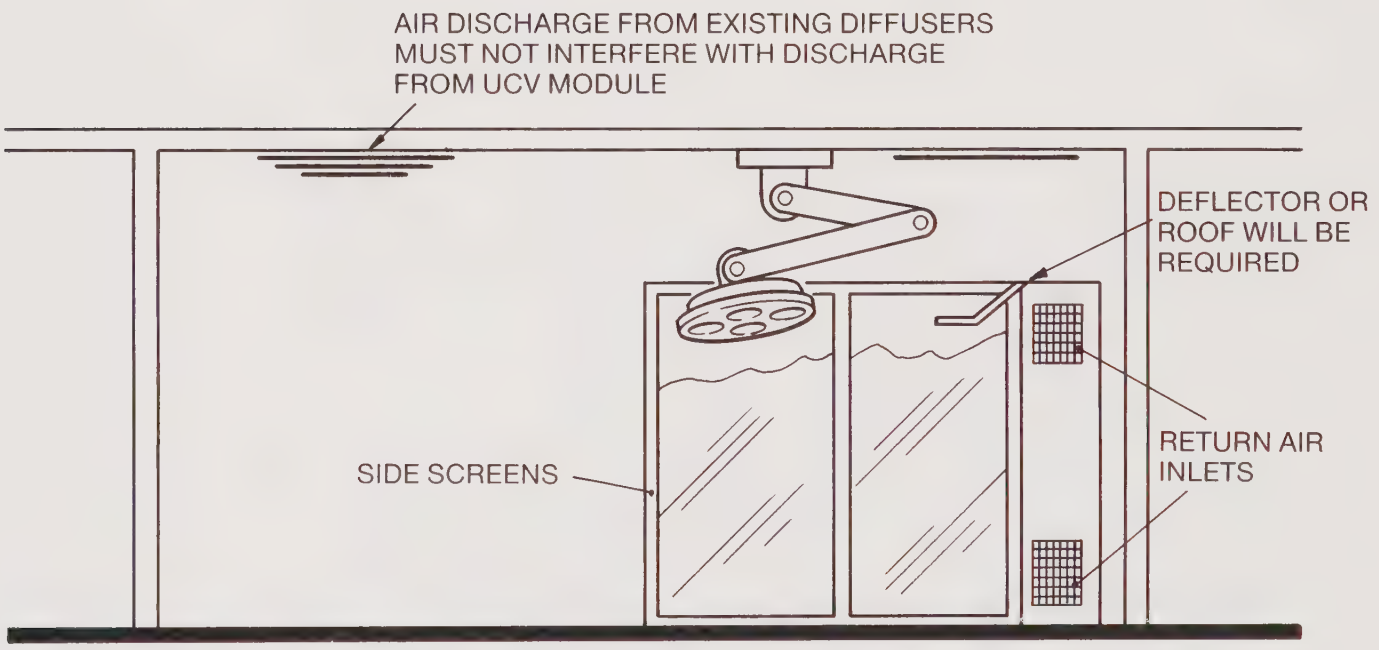


Figure 6.4 Typical horizontal UCV modular system

Performance of UCV system

6.69 Systems incorporating partial walls only are acceptable, but are known to be more susceptible to problems arising from poor operating team discipline, occupancy, and design parameters than is the case with full walls.

Choice of system

6.70 Vertical flow systems have a superior performance and are preferred. Remote systems will ensure that noise levels are minimal and provide the fewest restraints within the room. In addition, the handling point equipment can be maintained from outside the operating suite.

6.71 In an existing operating department, the only solution may be the installation of a modular system. The existing primary conditioning plant may require modification to ensure that the standards recommended are achieved.

6.72 Horizontal air flow systems are less effective and are not the preferred solution. There may be occasions, however, where architectural, engineering, economic or workload considerations prevent the installation of vertical flow systems, and only a horizontal flow system can be installed.

6.73 In the horizontal flow systems, personnel working between the filter and surgical wound will disperse bacteria which is more likely to enter the wound. This may be minimised by the use of improved clothing and operating procedure to reduce dispersion of bacteria.

6.74 The use of lines on the floor delineating the extent of the clean zone in all systems, and the "no-entry" zone in horizontal systems will assist staff and are therefore recommended (see Figures 6.4 and 6.5).

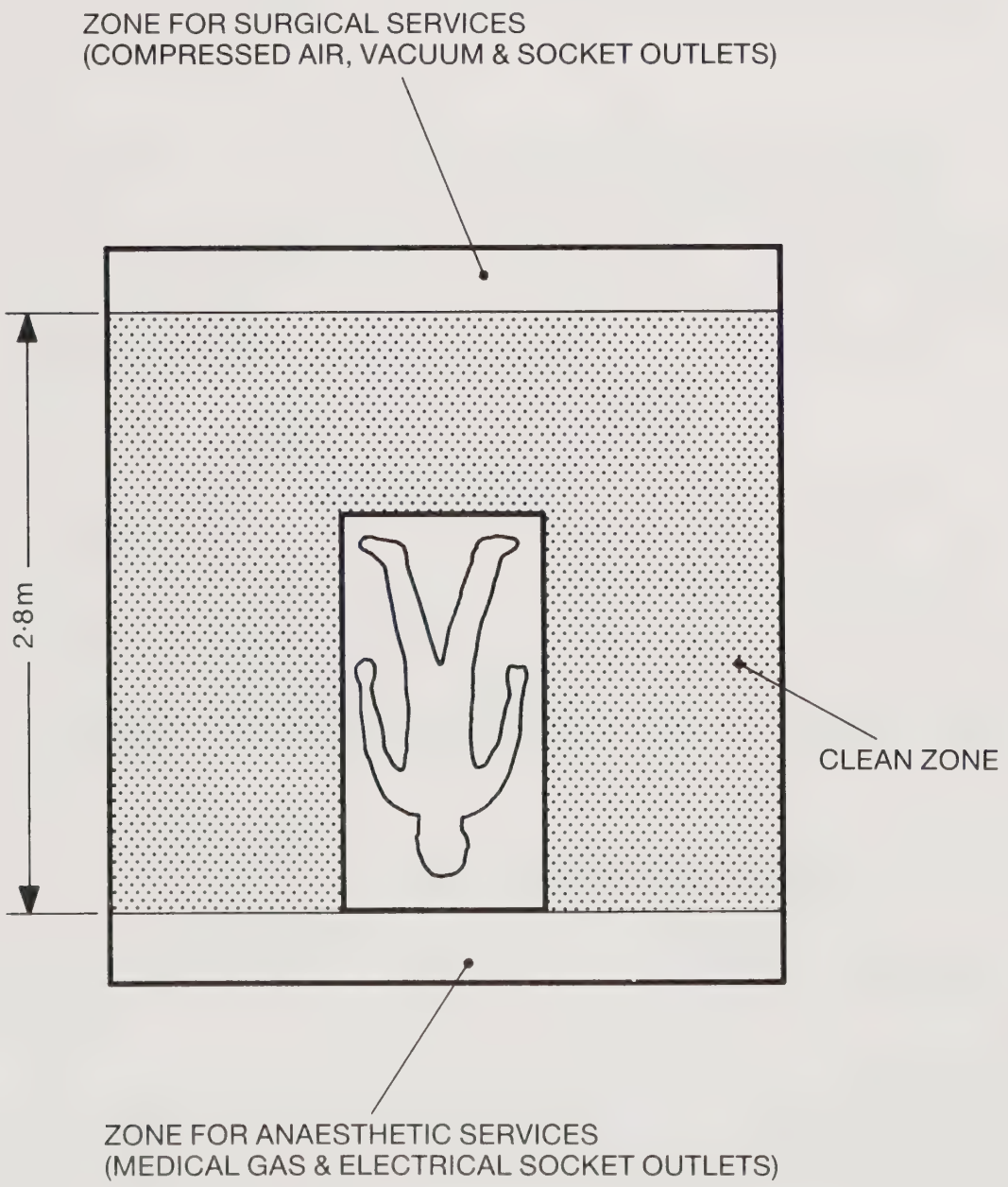


Figure 6.5 Plan of vertical flow supply

Design requirements

General

6.75 Vertical flow systems are preferred; they should have a minimum area of 2.8 m x 2.8 m. This is the area projected on a plan of the supply air terminal within the partial or full walls, with a clearance to the underside of the fixed partial wall of 2 m from finished floor level (FFL). Any air outside this zone should not be considered as ultra-clean although the level of microbiological contamination will be much lower than the general level in a conventional operating room. The system should have either fixed partial walls with demountable full-wall extensions, or fixed full walls down to at least 1 m above FFL.

6.76 Horizontal flow systems should have a minimum distance between the side wall panels of 2.4 m. The minimum height of the terminal should be 2.1 m. These dimensions reflect currently available equipment and may impose operational constraints in addition to a lower level of performance common in these systems.

Air movement scheme

6.77 There is no strict requirement when using a UCV system to have an air movement control system, except in the preparation room.

6.78 The inherent feature of a UCV system is its large air flow and it is essential to recirculate air to optimise energy savings.

6.79 The fresh air volume should be dispersed via the disposal room and other doors or openings from the operating room as required. The anaesthetic room can have balanced ventilation; this may be achieved by use of door grilles, under-cuts or other means.

6.80 If preparation rooms are intended to be used for "laying -up" they should have balance ventilation to avoid air transfers interfering with the ultra-clean air zone perimeter.

Discharge air velocities

6.81 To ensure that sufficient air reaches the operating plane, the discharge velocity is crucial. A number of factors either singly or collectively tend to prevent this:

a. uncontrolled short-circuiting;

b. heat emission from the operating lamp;

c. buoyancy effects resulting from the supply/room air temperature difference;

d. up-current generated by personnel;

e. the movement of staff within the zone.

6.82 The minimum discharge velocity is selected to take account of these factors and is greater than the theoretical minimum value.

6.83 At the suggested minimum discharge velocity, insufficient air will reach the working zone if the supply air temperature is greater than the room air temperature.

6.84 The minimum velocity of the discharged air as measured 2 metres above the FFL should be as shown in Table 6.8.

Table 6.8 Minimum discharge velocities

Vertical flow systems (velocity measured 2 m from FFL)		Horizontal flow systems
Full Walls terminating not more than 1 m above FFL (these walls may be demountable extensions of the fixed partial wall)	Fixed Partial Walls terminating 2 m above FFL	Measured 1 m from filter/ diffuser face
0.3 m/s average	0.38 m/s average	0.40 m/s

6.85 The minimum discharge velocity measured 1 m above FFL, for vertical flow systems should be 0.2 m/s.

6.86 Variable speed fans with differential pressure control may be the most suitable solution for maintaining consistent performance and energy saving (see also paragraphs 4.26 - 4.42).

6.87 Some UCV systems are designed to have a variable velocity over the working zone, the velocity decreasing from the centre towards the edge of the terminal. In such systems, the total air volume should be the same as uniform velocity systems of the same size and should otherwise satisfy the requirements of this guidance document.

6.88 When a system is designed to have partial walls with full wall extensions, a volume control facility may be incorporated to allow the system to be run with reduced velocity when the demountable full-walls are in place. It would be the responsibility of the user to ensure correct operation of the system, but to assist the user, a warning notice should be included on the control panel.

Filters

6.89 The main plant primary and secondary filters should be to the standards and in the location set out in paragraphs 4.87–4.104.

6.90 Terminal filters must be provided within or on the air supply to the uni-directional air flow terminal. High efficiency particulate air (HEPA) filters with a penetration of not greater than 5% when measured against BS3928 (Eurovent Grade EU9) will be required.

6.91 In some systems, the terminal filter is used as a pressure equaliser to balance air-flow and filters of greater pressure drop with a lower penetration may be required. This is acceptable, but there will be penalties in terms of the installed fan power and higher operating noise levels.

6.92 The final filters must be installed in a leakproof housing in a manner which ensures that the filter and its seal can be verified. A DOP test will be carried out during commissioning to prove the effectiveness of the complete installation; the design must allow access for the introduction of the DOP at least 2 metres upstream of the terminal filter. Some manufacturers can provide HEPA filter housings that enable a DIN 1946 housing seal leakage test to be carried out. These have the advantage that the test can easily be repeated using simple, non-specialist equipment as part of the systems monitoring procedures.

6.93 An EU3 grade recirculation/return air filter is required to capture relatively coarse particles which could otherwise significantly reduce the life of the final filter. Some manufacturers of filters believe that these are not necessary, as the larger particles will form a layer on the upstream face of the HEPA filter, thus increasing both its efficiency and capacity.

6.94 The design of the system must ensure that all terminal filters are easily accessible for monitoring and maintenance. An access point at least 2 m upstream of the terminal filter for the DOP test and a means of monitoring the pressure drop across all filters must be provided.

Controls and instrumentation

6.95 The controls and instrumentation for the main plant are set out in Chapter 5. UCV systems will additionally require:

a. a set-back facility to reduce the main supply air volume to 0.35 m^3/s by fan control, or (depending upon the operational policy) isolate the ventilation plant;

b. dirty terminal filter indication and alarm;

c. for modular systems, a means of selecting and indicating module running/set-back/off. Low air flow indication fan(s) failure indication;

d. a "system purging" run-up timer (minimum 5 minutes) linked to the plant start- up/restart from set-back control.

Noise levels

6.96 The total noise level for a remote plant system within the operating room should be no greater than L_{10} 50 dBA. For modular systems, whether vertical or horizontal flow, the maximum noise level should not be more than L_{10} 55 dBA.

6.97 The noise levels apply at the maximum velocity for which the system is designed to operate (see Table 3.3).

Air terminal

6.98 Vertical flow systems must either be designed to support the operating luminaire system, which typically should have a lowest point not less than 2 m above finish floor level (FFL), or allow the luminaire system to be fixed to the structural soffit of the room.

6.99 The plenum chamber and any ductwork downstream of the terminal filter must be clean and of high pressure (Class D) construction (see Figures 6.6 and 6.7).

Lighting

6.100 The general lighting in the theatre should give at least 500 lux at the working plane, and be as uniform as possible. Systems incorporating lighting within the terminal should be considered.

6.101 Specialised task lighting should be provided by thyroidal, cruciform or small multiple dome-shaped luminaires when vertical air flows are employed, as they have good aerodynamic properties. The larger (typically 1 m diameter) saucer-shaped luminaires supported from a central pillar will occlude the air flow in the critical central zone, and are not recommended for vertical flow systems, but may be used for horizontal systems where the lamp shape has little influence on the air flow.

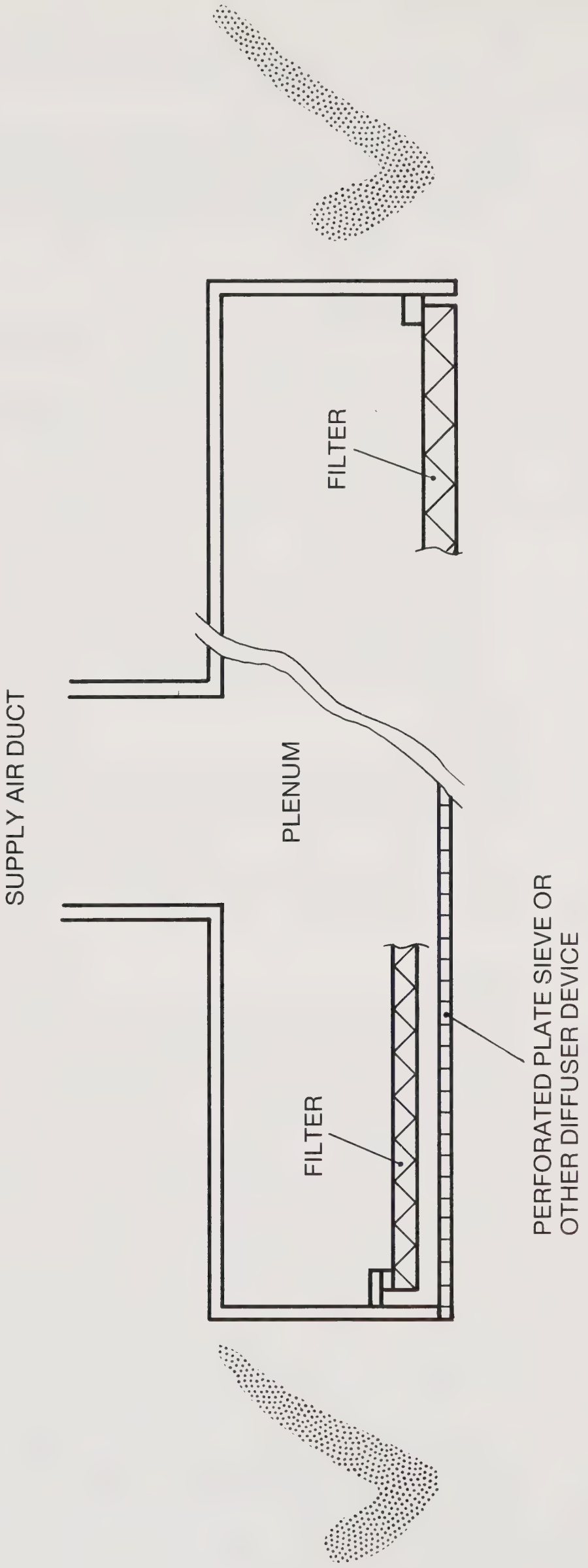


Figure 6.6 Methods of filter installation

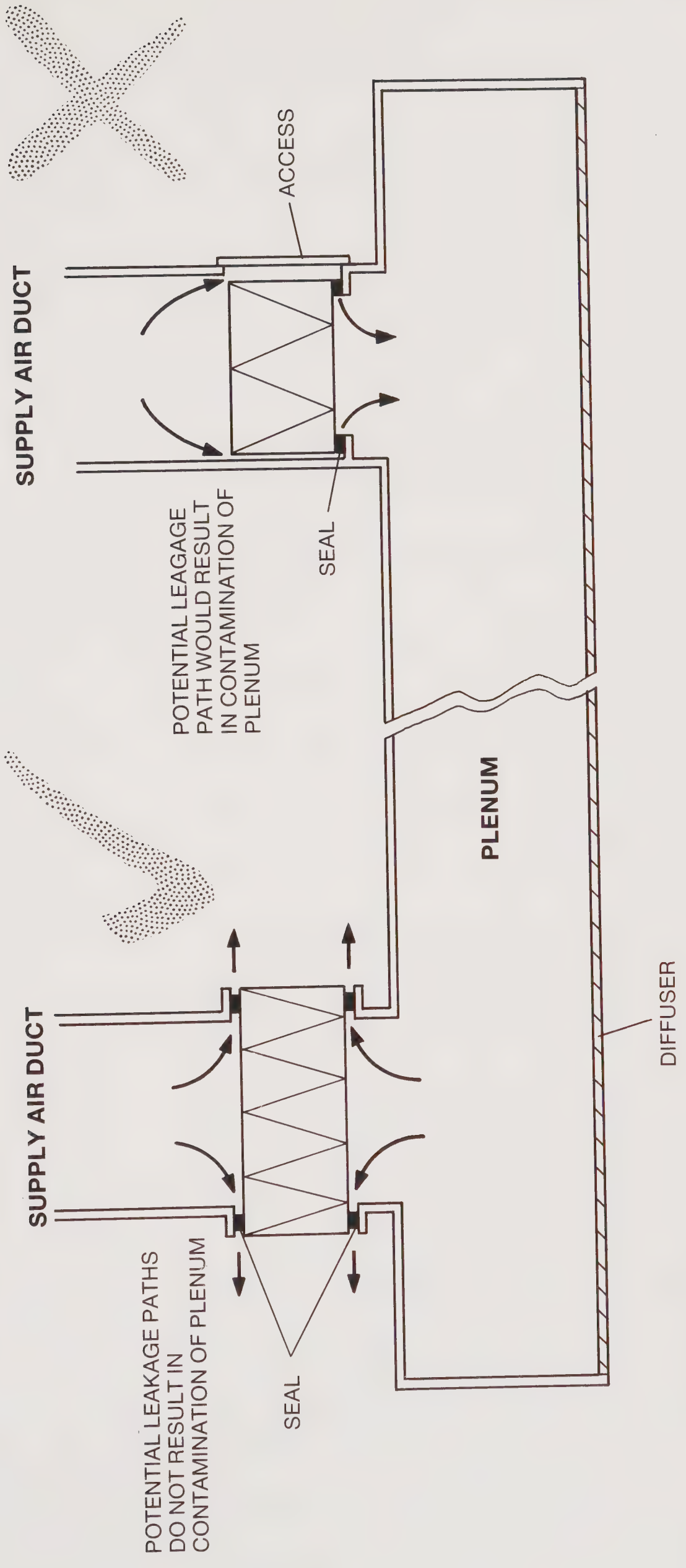


Figure 6.7 Methods of filter installation

6.102 Orthopaedic surgery normally requires a broad beam of light from the task lighting theatre luminaire. To achieve the best photometric results allowing the surgeon maximum flexibility of the luminaire, a minimum of 2.75 m from floor to underside of the diffuser of the UCV system is required to allow for supporting mechanisms.

6.103 New designs of operating luminaires should comply with the photometric requirements detailed in relevant sections of BS4533 and be mounted such that there is a clearance of 1 m between the underside of the luminaire and the operating table top.

The traditional means of light support is a central column ridiidily fixed to the building structure. Separate supports displaced from the centre of the clean zone would lead to improved air flow, but as yet no manufacturer has adopted this solution.

Hood extract systems

Special requirements

6.104 Extract canopies will be required over steam- and heat-emitting appliances, for example sterilizers, catering and washing equipment; and for the extraction of toxic fumes over benches used for mixing, sifting and blending procedures.

6.105 Perimeter drain gulleys and corrosion-proof grease eliminators should be provided on kitchen hoods.

Typical arrangements

6.106 The air-flow rate must be sufficient to ensure an adequate capture velocity in the vicinity of the process; typical values are as follows:

a. evaporation of steam and like vapours 0.25 m/s to 0.5 m/s;

b. chemical and solvent releases 1.0 m/s;

c. vapour or gases 5 m/s to 6 m/s;

d. light dusts 7 m/s to 10.0 m/s;

Excessive velocities will be wasteful of power and generate noise.

6.107 The lowest edge of the canopy should be 2 m above finished floor level, with a minimum of 300 mm overhang beyond the edge of the equipment on all sides.

6.108 A compact arrangement of equipment (but with access for maintenance) will minimise the canopy area, and hence reduce the air volume necessary to achieve the optimum capture velocity.

6.109 Hoods required for the control of heat gain and vapours may be connected to the general extract system when it is convenient to do so, but where non-corrosive ductwork materials are necessary, a separate discharge is preferred.

6.110 Lighting and internal divider plates are often required to be built into the perimeter of large canopies; however, built-in shelving systems are not recommended, as they interfere with the airflow, and constitute a maintenance problem.

Control of hood extracts

6.111 Provided that it does not interfere with the operation of the department when not in use, the ventilation system for the hood extract and any associated supply can be shut down. To this end, local control should be provided.

Bench extract systems

Special requirements

6.112 Bench extract ventilation is required in departments such as pathology and mortuary, where activities involve the release of malodorous or toxic fumes which should not be inhaled.

Typical arrangements

6.113 Each ventilated position will usually be accommodated in a continuous run of benching, which should not be more than 650 mm from front to rear and which should be provided with a continuous upstand at the rear. Each position should have a 1200 mm x 150 mm linear extract grille mounted on a purpose-designed plenum box (incorporating guide vanes as necessary), with its face flush with the upstand. The bottom of the grille should be as close as practicable to the level of the working surface (usually 75 mm above, to allow for cleaning). The minimum velocity across any part of the grille should be 1 m/s. The grille should be readily demountable to allow for cleaning.

Control of bench extract systems

6.114 Provided that it does not interfere with the operation of the department when not in use, the ventilation system for the bench extract and any associated supply can be shut down. However, a run-on timer with a minimum setting of 30 minutes must be provided. To this end, local control should be provided.

6.115 Glutaraldehyde mobile cabinets and work stations development are continuing to take place in the design of system using glutaraldehyde, generally used for the disinfection of scopes. These include totally enclosed processing machines to fume cupboard type of installation. Technical requirements and guidance is being developed and will be published when completed.

Safety cabinet and fume cupboard extract systems

Special requirements

6.116 The supply air system should not distort the uni-directional and stable air pattern required for fume cupboards and microbiological safety cabinets. In general, supply air ceiling diffusers should not discharge directly towards fume cupboards or safety cabinets, unless the terminal velocity is such that the air-flow pattern of the cabinet is unaffected. The design should ensure that high air change rates, and/or the opening and closing of doors do not have any adverse effect on the performance of safety cabinets or fume cupboards. A damped door closure mechanism may help.

Arrangements for safety cabinet installations

6.117 The manufacture and installation of microbiological safety cabinets must be in accordance with BS5726 and the 'Code of practice for the

prevention of infection in clinical laboratories and post-mortem rooms'. Further information on the selection and installation of these cabinets is contained in Health Equipment Information No 86. A Class 1 microbiological safety cabinet must be specified for routine work involving Group 3 pathogens.

6.118 Siting and installation of microbiological safety cabinets are of particular importance because:

a. the protection afforded to the operator by the cabinet depends on a specific and stable uni-directional air flow through the open front;

b. the protection afforded to the environment by the cabinet depends on the high efficiency particulate air (HEPA) filters. The exhaust air should never be considered as totally free from microbiological hazard.

6.119 Due to the HEPA filters, the discharge from safety cabinets is relatively "clean". Discharge to outside provides additional safeguards by dilution of any penetrating materials in the event of filter failure. In view of the hazard involved, it is usually preferable to provide short discharge ducts to atmosphere, through a wall or window or through the roof.

6.120 Where this is impracticable, discharge into the room via a double HEPA filter has been accepted; the preferred method however is to discharge above the roofline as per the standard for fume cupboard discharges.

6.121 BS5726 permits the installation of microbiological safety cabinets with integral fans, provided that the extract ductwork can be kept short (that is, less than 2 m); such an installation, however, is likely to be noisy and is not recommended for use in new buildings.

6.122 Roof-level discharge, wherever practicable, is preferred provided that this does not result in extensive and complicated extract ducts, since it removes much of the uncertainty over air re-entering the building through ventilation inlets and/or windows. In such an installation, the extract fan should be situated separate from the cabinet and close to the discharge outlet, to maintain the duct under negative pressure.

Laminar flow cabinets

6.123 Vertical laminar flow cabinets (BS5726 Class II) will be required for certain procedures (for example media preparation). They operate by drawing air from the laboratory and discharging filtered air uni-directionally over the work space.

6.124 They protect the media from contamination, but protection of the operator depends on the design of the cabinet and subsequent maintenance.

6.125 Limitations on the use of Class II cabinets are given in `Categorisation of pathogens according to hazard and categories of containment', Appendix A.

Arrangements for fume cupboard installations

6.126 The primary factors which contribute to the effective performance of fume cupboards include:

- an adequate volume of supply air;
- an effective exhaust system to promote the safe dispersal of waste products to atmosphere.

6.127 The air velocities through sash openings must be sufficient to prevent hazardous materials from entering the laboratory while avoiding excess flow rates that interfere with the investigation process. Average face velocities should be between 0.5 and 1.0 m/s, with a minimum at any point within 20% of the average, the upper end of the range being applicable to the containment of materials of high toxicity. The design velocity must be maintained irrespective of whether the sash opening is varied, or whether doors or windows are open or closed.

6.128 The possibility of a fire or explosion which may not be contained by a fume cupboard must always be considered. A fume cupboard should not, therefore, be sited in a position where exit to an escape route will necessitate passing directly in front of it.

6.129 Fume cupboard fans should be installed as near as possible to the termination of the duct, thus maintaining the maximum amount of ductwork at negative pressure.

6.130 Where there are adjacent buildings with opening windows, or where downdraughts occur, it may be necessary to increase the height of discharge ducts in order to achieve adequate dispersal. In complex locations, air-flow modelling or wind tunnel tests may be required to determine the optimum height of the stack.

6.131 Fume cupboards for certain processes must have separate extract systems; however, where appropriate, individual fume cupboard exhaust systems may discharge via non-return dampers into a single collection duct rather than having a large number of separate stacks. The collection duct should have a large cross-sectional area to minimise its effect on the individual exhaust systems; be open to atmosphere upstream of the first connection; and be designed to discharge a total air volume at least equal to the combined individual extract systems.

6.132 Individual fume cupboard extract systems, discharging either directly to atmosphere or into a collection duct, do not require duplex fans. However, a collection duct designed to provide dispersal of effluent from a number of individual extracts, should have duplex fans with automatic change-over.

6.133 Further detailed guidance concerning the selection and installation of fume cupboards is contained in Health Equipment Information No 86 and BS7258 'Laboratory fume cupboards' published in 1990.

Control of extract systems

6.134 It is desirable to provide local control of safety cabinets in order to maximise the life of the HEPA filter, and to permit the sealing of the cabinet and room for fumigation if spillage occurs.

6.135 To cope with the risk of an accident or spillage outside safety cabinets, a "panic button" should be provided to switch off the supply to that area; and discharge all extracted air to atmosphere.

6.136 In pathology departments, it will be necessary to have one or more microbiological safety cabinets and one or more fume cupboards available for use at all times, including weekends. Therefore, local overriding controls for all these items and any associated ventilation plant will be necessary.

Plantroom ventilation

General requirements

6.137 Plantrooms are required to be ventilated in order to maintain acceptable temperatures for satisfactory operation of the plant and controls, and for maintenance activities. In the case of plantrooms containing combustion equipment, a secondary function of the ventilation air is to provide make-up air for the combustion process.

6.138 The air required for these purposes should be introduced into the space through inlets positioned to minimise the discomfort to occupants; they should be unlikely to be blocked, closed deliberately (except in the case of fire shutters if required), or rendered inoperative by prevailing winds.

6.139 Plantroom ventilation air should not be used for any other purposes, such as make-up air for extract; and where the plantroom contains combustion equipment, the appliance pressure must not fall below the outside air pressure.

6.140 Statutory regulations for plantroom ventilation are contained in the Building Regulations, and further guidance in section B13 of the CIBSE guide.

Assessment of ventilation levels

6.141 Ventilation requirements must take into account all heat sources within a plantroom, and where there are large glazing areas, solar gains. The ventilation rate should limit the maximum temperature within the plantroom to 32°C.

6.142 As the level of equipment operating during mid-season and summer is often lower than the winter condition, and the cooling effect of the outside air is reduced, it is necessary to calculate the minimum volume for each season of operation, and the inlet and outlet grilles or fan sizes should be chosen to cater for the largest seasonal air volume.

6.143 Replacement air should not be drawn through pipe trenches or fuel service ducts. Where metal ducts penetrate walls and floors, effective sealing should be provided to confine the ventilation to the boiler room and to meet fire protection requirements. Penetration of fire barrier walls by ventilation ducts should be avoided if possible.

6.144 Fire dampers in ventilation ducts should be electrically interlocked with the boiler plant.

6.145 Care must be taken to prevent any noise generated in the boiler room emerging from natural or mechanical ventilation openings to the detriment of the surrounding environment. Particular care is necessary with mechanical flue draughts and fan-diluted flue systems.

6.146 Information on required air volumes is contained in section B13 of the CIBSE guide.

6.147 Where combustion plant is installed, the high-level (outlet) openings should be sized to cater for the total ventilating air quantity; and the low-level (supply) openings sized to cater for the total combined ventilating and combustion air quantity.

Choice of ventilation system

6.148 The ventilation air may be introduced and exhausted by either natural or mechanical means or a combination of both; however, where possible, natural systems are preferred.

6.149 Generally, small installations at or above ground level should have their combustion and ventilation air provided by natural means, employing both high and low-level openings.

6.150 Basement, internal and large installations at or above ground level will usually require a combination of natural and mechanical ventilation. If the air-flow route is difficult, both supply and extract may require mechanical means.

6.151 Whether natural or mechanical, the system should be designed to avoid both horizontal and vertical temperature gradients. Both inlet and outlet openings should be placed on opposite or adjacent sites of the building to reduce the effect of wind forces.

6.152 Where mechanical air supply is employed, electrical interlocks with the boiler plant should be provided to prevent damage in the event of failure of the supply fan(s) once the air volume is established.

6.153 The necessary free opening areas for a naturally ventilated plantroom may be calculated using either the method in A4 of the CIBSE guide, or the table in section B13.

6.154 A combined natural and mechanical ventilation system should allow for natural extract at high level, to take advantage of convective forces in the room, with mechanical supply at low level. The high level natural ventilators should be sized to cope with the total quantity of ventilation air, as above.

6.155 To prevent leakage of flue gases and to ensure that the flue draught is not impeded at any time, the air pressure in the boiler room must not exceed the prevailing outside pressure. Therefore, the fan duty should exceed the calculated total combined combustion and ventilation air quantity by at least 25%. Fan-powered inlets should be arranged to flow outside air into the space at a point where cross-ventilation will ensure pick-up of heat without causing discomfort to the occupants.

6.156 Where it is impractical to provide sufficient natural ventilation to remove the heat emitted by the plant, both mechanical supply and extract will be required.

6.157 The high-level extract should be sized to cater for the total ventilating air quantity and the low-level supply should exceed the total combined combustion and ventilating air quantity by at least 25%, as above.

Ventilation of hydrotherapy suites

Special requirements

6.158 The Departmental Cost Allowance for a hydrotherapy suite includes for heat recovery via a heat pump system.

Arrangements for hydrotherapy pool installations

6.159 The quantity of supply air should be calculated as 25 litres/sec/m^2 wetted surface, with the wetted surface taken as 110% of the pool water surface area.

6.160 A recirculation plant is recommended, with a minimum of 20% fresh air.

6.161 As far as practicable, recirculated pool air should be provided to the ancillary changing and recovery accommodation, with the only extract from the toilets, laundry/utility room and pool hall.

6.162 Supply air to the pool hall should be introduced at high level and directed towards the perimeter to mitigate condensation, with extract air taken from directly over the pool.

Control of hydrotherapy pool installations

6.163 The supply and extract fans should be interlocked so that the supply fan does not operate until flow is established within the extract system.

6.164 Time-clock control should be provided, with a local override switch to extend the normal operating period as required.

6.165 Night set-back temperature (in the range of 21–25°C) and high humidity control (in the range of 60–75% sat) should be provided to override the time-clock in order to prevent condensation. The exact set points should be ascertained post-installation.

6.166 A remote indication panel should be provided in the pool hall, giving a visual display of the pool water and pool air temperature.

7.0 Commissioning

General

7.1 Commissioning is an essential process for ductwork systems, and if the needs of on-site regulation are not foreseen and provided for in the design stage, balancing the system within accepted limits may never be possible. Procedures for commissioning air-handling systems are given in CIBSE Commissioning Code A and in BSRIA Application Guide 1/75. The "Validation and verification" volume of this HTM sets out commissioning procedures.

7.2 The duct sizing procedure should take into account the requirements of system balancing, and the position and number of regulating dampers included in the design should be sufficient for this purpose.

Location of dampers and test holes

7.3 Balancing/commissioning dampers will be required in each branch of the distribution ductwork.

7.4 Test holes for the measurement of air-flow will be required at carefully selected points in main and all branch ducts. Their positions must be identified at the design stage. The test positions should be located in a straight length of duct, so that accurate measurement can be made, and generally in the following positions:

a. on both sides of the fans and heating and cooling coils (for pressure drop measurements);

b. in the main ducts;

c. in all branches;

d. in centrifugal fan drive guards, opposite the end of the fan spindle, for speed measurements.

7.5 The number and spacing of holes at a particular location are given in BSRIA Application Guide 1/75.

7.6 The actual location for the measurement point should be chosen:

a. at least 1.5 duct diameters upstream of sources of turbulence such as dampers and bends;

b. if this is not possible, 10 diameters downstream of dampers bends or tees, and 5 diameters downstream of eccentric reducers;

c. where there is enough space round the duct to insert the pitot tube and take readings;

d. where the duct has a constant cross-sectional area.

7.7 Test holes for measuring total air flow from a fan should be located either 4 diameters upstream, or 10 diameters downstream of the fan.

Information to be provided

7.8 It is essential that the designer should pass on his intentions fully to the commissioning engineer by indicating which parts of the system are high, medium and low pressure, and by providing:

a. relevant parts of the specification;

b. schematic drawings indicating data listed in Table 7.1;

c. equipment schedules;

d. controller and regulator schedule;

e. fan performance curves;

f. wiring diagrams for electrical equipment, including interlock details.

Table 7.1 Information to be provided on schematic drawings

Items of system	Information to be provided
Fans	Fan total pressure
	Volume flow rates
	Motor current
Plant items	Type and identification numbers from equipment schedules
	Volume flow rates
	Pressure losses
	Dry bulb temperatures
	Wet bulb temperatures
	Humidity
Dampers, including motorised and fire dampers	Identification numbers from equipment schedules
	Location
	Volume flow rates
	Location
Main and branch ducts	Dimensions
	Volume flow rates and velocities
	Identification numbers from equipment schedules
Terminals	Location
	Dimensions
	Volume flow rates and velocities
	Operating pressures
Test holes and access panels	Location
Controllers	Set points

Notes:

1. Fan total pressure is the difference between the total pressure (static pressure + velocity pressure) at the fan outlet and the total pressure at the fan inlet.
2. Where volume flow rates are variable, maximum and minimum values should be provided.

Appendix 1

Design of air movement control schemes for operating suites

General

1.1 The standard plans are given in paragraph 6.1. If these standard solutions cannot be used, the following procedure should be adopted, which will result in an acceptable design.

1.2 The method is concerned with the calculation of air-flow rates, to ensure that correct air movement occurs between rooms when any one door is open. Under most circumstances the air quantities required for air movement control will approximate to those for either temperature control or bacterial contaminant dilution and the air-flow rate to the operating department will not exceed 1 m^3/sec. This flow rate is sufficient to control the effects of any slight reverse flows occurring when a door is opened.

1.3 The progression through the design procedure is shown in the Air flow design procedure chart, Figure A1, and is supported by the worksheets WS1 to WS7 described below. It is recommended that a plan of the suite and an air-flow network be made to collate all information. Flow rates, air transfer devices etc are entered as required. The remainder of this Appendix may be treated as reference data to assist in the various steps. The following symbols are used:

a. S_S – supply air-flow rate for summer temperature control;

b. S_W – supply air-flow rate for winter temperature control;

c. S_D – supply air-flow rate for dilution of bacterial contaminants;

d. E_D – extract air-flow rate for dilution of bacterial contaminants;

e. S_F – final supply air-flow rates;

f. E_F – final extract flow rates;

g. S_{AMC} – air supply flow rate for air movement control;

h. E_{AMC} – air extract flow for air movement control.

1.4 To simplify the procedure standard worksheets WS1 to WS7 have been devised. For each operating suite a set is required comprising one each of WS1, WS3, WS5, WS6 (a), WS6 (b) and WS7, one WS4 for each corridor and one of WS2 to cover each peripheral room. WS2 has five versions, WS2a single flow, WS2b parallel/series multi-flow, WS2c parallel multi-flow or series multi-flow (unbalanced), WS2d series multi-flow (balanced) and WS2e Bay (semi-open).

Peripheral room types

1.5 The rooms in the operating suite other than the operating room and corridor are referred to as peripheral rooms. Peripheral rooms have been classified according to the flows in and out. These room classifications are under the headings below.

Step	Description	Worksheet
1	Show nominal room pressures and air flow directions on the plan (fig. C1) and WS1	WS1
2	Enter heat/loss/gain data and calculate supply air flow rates for temperature control only. Categorise room types, e.g. sterile, clean, etc.	WS1
3	Enter air flows required for bacterial contamination control, add supply and extract volumes (Sd, Ed) on plan (fig. C1)	WS1
4	Define peripheral room types, see clauses B2 and B3 and select appropriate worksheets	Select from WS2a to WS2e
5	Locate air transfer devices, enter details on worksheets and locate on figures C1 and C2	Selected worksheets from WS2a – WS2e
6	For each peripheral room determine air flows through doors when open and calculate mechanical supply or extract and transfer device flows	as above
7	Select 'Key Door' and calculate air supply for operating room	WS3
	Does this door produce solution with greatest flow — NO (return to step 7) / YES	
8	Transfer to WS1 and select final rate S_F and E_F	WS1, WS3
	Does S_F to OR exceed 1.0 — YES → Reduce S_F to 1.0 correct WS1 / NO	
9	Make provision for relief of excess air with doors closed	Selected worksheets & WS3
10	Calculate supply and extract flow rates for corridor(s).	WS4 WS5
11	Calculate room temperatures (all doors closed) and ΔT's	WS6a & WS6b
	Do any Δts across doors to sterile rooms exceed 1.0°C — YES → Rectify as in clause B9 / NO	
12	Make summary of flows	WS6a & WS6b
13	Size transfer devices, size ductwork, central plant, etc.	WS7
14	Design ductwork layout, control plant, etc.	–

Figure A1 Air flow design procedures

Single flow

1.6 This is a room with only one door and a nett surplus of supply or extract air.

Parallel multi-flow

1.7 This is a room with two or more doors through each of which the air flows either outwards (high pressure) or inwards (low pressure) (for example lay-up plan 1b).

Parallel/series multi-flow

1.8 This is a room having a nett surplus of supply or extract and with two or more doors. One or more doors will be to an area of equal cleanliness and need not be protected, hence the flow may vary between inwards and outwards, the remaining door being to an area of greater or lesser cleanliness (for example a sterile pack store plan 1a).

Series multi-flow (unbalanced)

1.9 This is a room having a nett surplus of supply or extract and with two or more doors. Air flows inwards through one or more doors and outwards through one or more doors.

Series multi-flow (balanced)

1.10 This is a room as in paragraph 1.9 above but having either no mechanical ventilation or no nett surplus of supply or extract (for example an anaesthetic room).

Bay

1.11 A room which has a permanent opening to the operating room may be considered as a bay off the latter (for example a scrub). Two categories exist:

a. open bay – the opening is larger than a normal single door opening. The bay may be considered as part of the main room;

b. semi-open bay – the opening is no larger than a normal single door opening. In this case it is possible to protect the bay from the main room by provision of air supply or extract in the bay, or by passing air to or from another area.

Calculation Sheet for Flow-rates			**Worksheet WS 1** Reference:			
Room Name						
1. Summer temperature control Heat gain	kW					
2. Acceptable Δt	°C					
3. Air flow rate (S_G) $= \frac{\text{Gain}}{\Delta t \times 1.2}$	m^3/s					
4. Winter temperature control Heat loss	kW					
5. Acceptable Δt	°C					
6. Air flow rate (S_L) $= \frac{\text{Loss}}{\Delta t \times 1.2}$	m^3/s					
7. Dilution of bacterial contaminants Air flow-rate	m^3/s					
S_D or E_D						
8. Maximum of S_G, S_L, S_D or E_D	m^3/s					
9. Air movement control Air flow rate for air movement control S_{AMC} or E_{AMC} (From WS2, WS3 or WS4)	S m^3/s					
	E m^3/s					
10. Final supply flow-rate (S_F)	m^3/s					
11. Final extract	m^3/s					
12. Total supply		m^3/s				
13. Total extract		m^3/s				

SAMPLE

Air Movement Control
Peripheral room ..... type, single flow

Worksheet WS 2a
Reference:
Nominal pressure: Pa

Consider door to ..... open.

			Air flow, m^3/s		
	Pa	Δt	Out	In	Remarks
Flow required through doorway to give protection					
Structural leakage					
Total					

S_{AMC} $(\Sigma_{OUT} - \Sigma_{IN})$ ☐ m^3/s.
or
E_{AMC} $(\Sigma_{IN} - \Sigma_{OUT})$ ☐ m^3/s.

Transfer S_{AMC} or E_{AMC} to WS1.

Consider door to ..... closed,

	Pa	Δt	Out	In	Remarks
Closed door leakage					
Structural leakage					
Total					

Return S_F and E_F to WS1. ☐ ☐

Flow through transfer grille outward $(S_F - E_F - L_{OUT})$. ☐
or
Flow through transfer grille inward $(E_F - S_F - L_{IN})$. ☐

SAMPLE

Air Movement Control **Peripheral room** ..... type, parallel/series multi-flow	**Worksheet WS 2b** Reference: Nominal pressure: Pa

Door from this room to ..... (room of equal cleanliness) is not to be protected.
A transfer grille is located in, or adjacent to, this door.

Consider other door to ..... open.

Room pressure now becomes [25] or [3] or [ ] Pa. (See table 6.2.)

			Air flow m^3/s		
			Out	In	Remarks
Flow required through open doorway to give protection					
At above pressures leaks through closed doors	Pa	ΔP			
Mechanical supply/extract S_F/E_F					
Total					

X ($\Sigma_{OUT} - \Sigma_{IN}$) [ ] or Y ($\Sigma_{IN} - \Sigma_{OUT}$) [ ]

Transfer grille required

From high pressure zone Flow = X

or [ ] at [ ] ΔPa.

To low pressure zone Flow = Y

Size of transfer grille (free area) A1 [ ]

Consider doors and hatch closed – Room pressure becomes [ ] Pa. (nominal)

Closed door leakage from table 6.4 (assuming no transfer grille)	Pa	ΔP	Out	In	Remarks
Mechanical supply extract					
Structural leakage					
Total					

Air flow required through transfer grille = IN - OUT = Z′ [ ]

or OUT - IN = Z″ [ ]

Transfer grille required flow Z′ or Z″ [ ] @ [ ] ΔP.

Size of transfer grille (free area) A2 = [ ]

Select larger of A1 or A2. [ ]

SAMPLE

Air Movement Control **Peripheral room ..... type, parallel multi-flow high/low or series multi-flow (unbalanced)**	**Worksheet WS 2c** Reference: Nominal pressure: Pa

Consider door from this room to ..... open.
Room pressure now becomes [ ] or [ ] or [ ] Pa. (See table 6.2.)

			Air flow, m^3/s		
			Out	In	Remarks
Flow required through open doorway to give protection					
At above pressures leaks through closed doors are:—	Pa	ΔP			
Structural leaks					
		Total			

S_1 ($\Sigma_{OUT} - \Sigma_{IN}$) [ ] or E_1 ($\Sigma_{IN} - \Sigma_{OUT}$) [ ]

Consider door from this room to ..... open.
Room pressure now becomes [ ] or [ ] or [ ] Pa.

			Out	In	Remarks
Flow required through open doorway to give protection					
At above pressures leaks through closed doors are:—	Pa	ΔP			
Structural leaks					
		Total			

S_2 ($\Sigma_{OUT} - \Sigma_{IN}$) [ ] or E_2 ($\Sigma_{IN} - \Sigma_{OUT}$) [ ]

Consider doors closed.
Closed doors leakage from table 6.4.

Door to:	Pa	ΔP	Out	In	Remarks
Structural leaks					
		Total			

Return S_F and E_F from WS1. [ ]
Flow through transfer device outward ($S_F - L_{OUT}$) [ ] to .....
or
Flow through transfer device inward ($E_F - L_{IN}$) [ ] from .....
Transfer grille [ ] Pressure relief damper [ ]

Air Movement Control **Peripheral room ..... type** **series multi-flow (balanced)**	**Worksheet WS 2d** Reference: Nominal pressure: Pa

Note:– In this type of room the supply and extract air-flow rates are equal and take no part in the air movement control (AMC).

Firstly open door to higher pressure area.

Room pressure then becomes [25] or [17] or [ ] Pa. (See table 6.2.)

			Air flow m^3/s		
			Out	In	Remarks
Flow required through open doorway to give protection. See table 6.2.					
At above pressures leaks through closed doors are:–	Pa	ΔP			
Structural leakage					
Total					

Q_1 ($\Sigma_{IN} - \Sigma_{OUT}$) [ ] (+ ve inwards)

Next, open door to lower pressure area

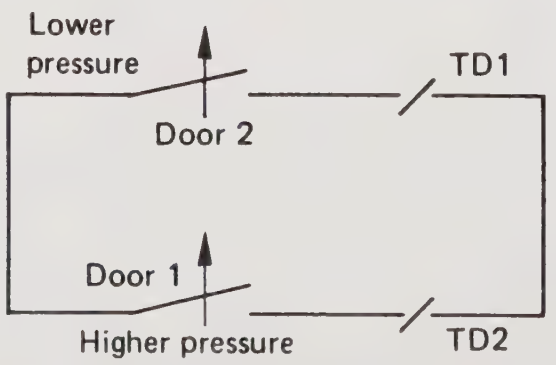
Room pressure then becomes [ ] or [ ] or [ ] Pa.

			Out	In	Remarks
Flow required through open doorway to give protection.					
At above pressures leaks through closed doors are:	Pa	ΔP			
Structural leakage					
Total					

Q_2 ($\Sigma_{OUT} - \Sigma_{IN}$) [ ] (+ ve outwards)

Flow through transfer device (TD1) to protect door 1 = Q_1 [ ] at resultant ΔP .....

Flow through transfer device (TD2) to protect door 2 = Q_2 [ ] at resultant ΔP .....



Air Movement Control **Peripheral room ..... type bay** **(semi-open)**			**Worksheet WS 2e** Reference: Nominal pressure: Pa		
Note:— If the room is of the open bay type (i.e. opening is larger than normal single doorway) the room should be considered as part of the main room. No air movement control considerations need then be made, and this sheet can be discarded. Supply and/or extract flow will be based on air distribution considerations.					
Consider permanent opening					
			Air flow, m^3/s		
			Out	In	Remarks
Flow required through opening to give protection.					
Leaks through closed doors to:	Pa	ΔP			
Structural leakage					
Total					
E_{AMC} [ ] or flow outward through transfer device. ($\Sigma_{IN} - \Sigma_{OUT}$) [ ]					
Transfer S_{AMC} or E_{AMC} to WS1.					
Transfer device — transfer grille [ ] pressure stabilizer [ ]					
Size select transfer device for flow rate [ ] @ ΔP [ ]					
Note:— A door from the bay is considered with the peripheral room to which it leads or if it leads to the corridor it is considered with the main room.					

SAMPLE

Air Movement Control **Operating room**	**Worksheet WS 3** Reference: Nominal pressure: Pa

Note:– To avoid considering each door open in turn the "key door" concept is introduced. This is the door which requires the greatest mechanical flow when open. See guidance clause B5.2.

Select "key door" (see above).

Consider this door open – room pressure now becomes [ ] Pa. (See table 6.2.)

See B.3 for room pressures.

			Air flow m^3/s		
			Out	In	Remarks
Flow required through doorway to give protection.					
Air flow "out" or "in" via doors transfer devices, etc.	Pa	ΔP			
Structural leakage					
Mechanical extract					
Total					

S_{AMC} ($\Sigma_{OUT} - \Sigma_{IN}$) [ ] transfer S_{AMC} to WS1.

Consider all doors closed.

Return S_F from WS1. [ ] Room pressure now [ ] Pa. (nominal)

Air flow 'out' or 'in' via door leakage transfer devices, etc.	Pa	ΔP	Out	In	Remarks
Structural leakage					
Mechanical extract & supply					
Total					

Flow (Σ_{IN} Σ_{OUT}) through transfer device [ ] @ ΔP [ ] to .....

For final selection of transfer device see B7.

SAMPLE

Air Movement Control Corridor			**Worksheet WS 4** Reference: Nominal pressure: Pa		
Consider all doors closed.					
			Air flow m^3/s		
			Out	In	Remarks
Flow required through doorway to give protection.					
Leaks through closed doors, transfer devices, permanent openings, etc.	Pa	ΔP			
Total flow inwards (SI)					
Add mechanical input (S_2)if necessary to increase SI to give 7 A/C per hour.					
Total flow outwards and inwards					
$S_{AMC} = (\Sigma_{OUT} - \Sigma_{IN} + S_2)$ ☐ Transfer to WS5					
or $E_{AMC} = (\Sigma_{IN} - \Sigma_{OUT} + S_2)$ ☐ Transfer to WS5					

SAMPLE

Air Movement Control	**Worksheet WS 5** Reference:	
Summary of air supply and extract for an operating suite		
Air flow to corridor	All doors closed	Anaesthetic (key door open)
	m^3/sec	m^3/sec
From preparation		
From operating room		
From scrub		
From anaesthetic		
Total (a)		
Air flow to corridor From disposal		
From other source		
Total (b)		
Structural leakage total (c)		
Other room supplies ..... Total (d)		
Total air supply a + b + c + d		
Consider corridor ventilation (see table 6.1) and calculate air volume required, based on 7 A/C per hour.		
		m^3/sec
Air flow required to ventilate corridor		
Air flow required to ventilate corridor		
If the air-flow from the operating suite (a) and (b) is greater than the calculated required volume, no further supply air is necessary		
		m^3/sec
Additional air to ventilate corridor		
Additional air to ventilate corridor		
Air extract The size of the extract plant should be sized in the order of 10% below the supply to assist in maintaining the department under positive pressure relative to the outside departments.		
		m^3/sec
Extract plant = Supply less leakage		
Less 10% of supply		
Total extract		
Note:– The extract volume includes 0.15 m^3/sec from the anaesthetic room for a balanced condition.		

Room temperatures — summer

Worksheet WS 6 (a)
Reference:

Find summer supply temperature $t_{(s)} = 20 - 0.828 \frac{H(O/R)}{Q(O/R)}$ = Tss ____ °C

Note: The temperature of a space may be calculated from

$$T = \frac{t_1 Q_1 + t_2 Q_2 + \ldots\ldots + t_n Q_n + (0.828H)}{\Sigma Q}$$

Where t_1 is temperature of source 1 (°C)

Q_1 is flow from source 1 when all doors are closed (m^3/s)

H is heat gain in space kW

Room	Heat gain kW H	Supply		Flows inwards										Temperature °C T
				From . .		From . .		From . .		From . .		From . .		
		Q	t_s	Q	t	Q	t	Q	t	Q	t	Q	t	

Check doors to sterile areas

Door between	Calculated room ΔT (°C)	Maximum ΔT permitted	Remarks

SAMPLE

Room temperatures — winter	**Worksheet WS 6 (b)** Reference:

Find winter supply temperature $t_{(s)} = 22 - 0.828 \frac{H(O/R)}{Q(O/R)}$ = Tsw ____ °C

Note: The temperature of a space may be calculated from

$$T = \frac{t_1 Q_1 + t_2 Q_2 + \ldots\ldots + t_n Q_n + (0.828H)}{\Sigma Q}$$

Where t_1 is temperature of source 1 (°C)

Q_1 is flow from source 1 when all doors are closed (m^3/s)

H is heat gain in space kW

Room	Nett heat loss kW H	Supply		Flows inwards										Temperature °C T
				From . .		From . .		From . .		From . .		From . .		
		Q	t_s	Q	t	Q	t	Q	t	Q	t	Q	t	

Check doors to sterile areas

Door between	Calculated room ΔT (°C)	Maximum ΔT	Remarks

SAMPLE

Transfer grilles, pressure relief dampers and pressure stabilizers	**Worksheet WS7** Reference

Transfer grilles – see clause B.5

No	Location	Pressure difference Pa	Flow rate m^3/s	Free area m^2	Model	Resultant Δp Pa	Remarks

Pressure relief dampers – see clause B.6

No	Location	Pressure difference Pa	Flow rate m^3/s	Free area	Pressure setting Pa	Remarks

Pressure stabilizers – see clause B.7

Note: Where a stabilizer is acting both as series room door protection and operating pressure control, 'pressure difference' and 'flow rate' are from WS2d 'pressure setting' is from WS3.

No	Location	Pressure difference Pa	Flow rate m^3/s	Free area	Pressure setting Pa	Remarks

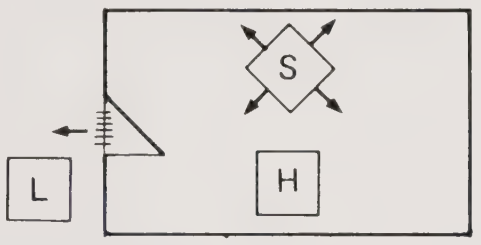
SAMPLE

Air movement control in peripheral rooms

1.12 For the design of air movement control, three types of air transfer device are considered. These are transfer grilles, pressure relief dampers and pressure stabilisers. Each has a particular field of application within the design as described in paragraphs 1.32–1.39. Air movement is controlled in each of the different room types below.

Single flow rooms

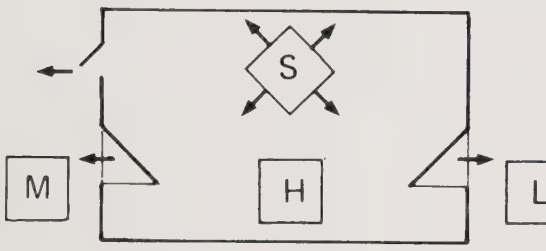
1.13 An appropriately sized transfer grille should be located in or adjacent to the door of each single flow room to relieve the pressure difference across the door when closed.



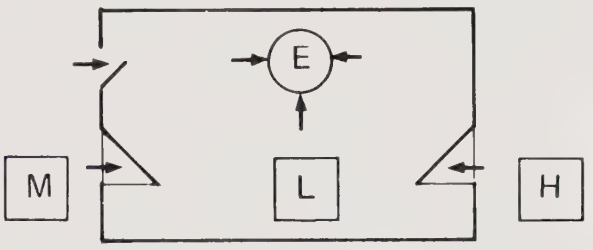
Single flow

Parallel multi-flow rooms

1.14 The pressure difference across the closed doors must be relieved but transfer grilles are not appropriate where two doors lead to areas of different pressures, because reverse flow could occur when the other door is open. For this reason, pressure relief dampers are used.



Parallel multi-flow
(high pressure room)



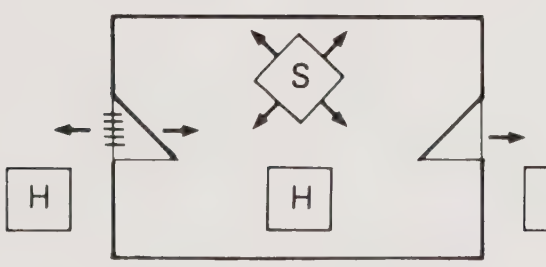
Parallel multi-flow
(low pressure room)

1.15 These rooms will be either high pressure or low pressure with respect to the adjacent areas. See preparation lay-up room in Plan 1b and disposal room in Plan 1b respectively. The pressure relief damper is always situated between the room and area, which results in the smaller differential pressure to ensure best use of air.

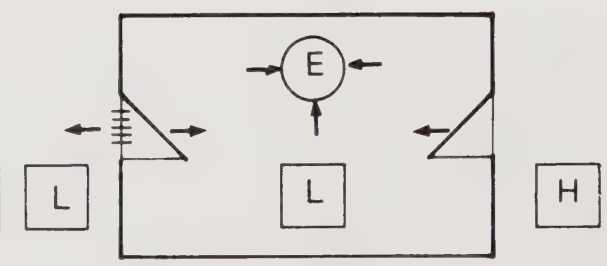
1.16 Just as reverse flow can occur if transfer grilles are used, it can similarly occur via door gaps when the other door is opened. It is not possible to avoid this, except by using air locks, but due to the low flow-rates and short durations involved, this is not considered to be of importance.

Parallel-series multi-flow rooms

1.17 These rooms are similar to those in paragraph 1.14 above, but because the room is of equal cleanliness to one of the adjacent rooms the nominal pressures will be equal and air may flow through the adjoining doorway in either direction for example, the prep-sterile pack store in Plan 1a.



Parallel series multi-flow



Parallel series multi-flow

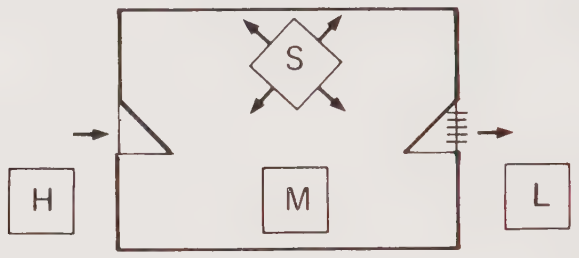
1.18 Where the nominal room pressure equals that of the higher pressure adjacent room, the best use of air is by supplying air required for bacterial dilution only and allowing this to exhaust via a transfer grille to the area of equal cleanliness. The doorway to the lower pressure area is protected by the combination of the supply air and the air which will flow inwards through the transfer grille from the area of equal cleanliness.

1.19 Conversely, where the nominal pressure equals that of the lower pressure adjacent room, extract ventilation and a transfer grille to the lower pressure adjacent room should be provided for example, the disposal room in Plan 5a.

Series multi-flow (unbalanced)

1.20 These rooms are somewhat similar to those in paragraph 1.15 above, but because the pressure lies between that of the rooms on either side, the back-flow problem does not exist.

1.21 Where the room has a nett surplus of mechanical supply air, a transfer grille should be located in or adjacent to the door through which air flows outwards and the mechanical supply flow rate to the room should be chosen to give protection when this door is open.



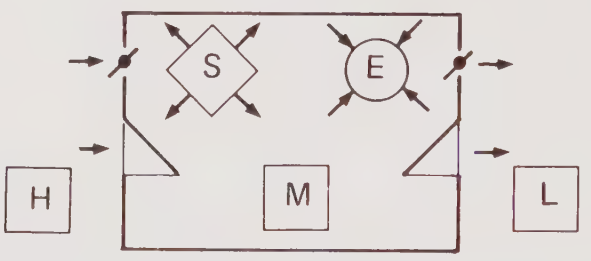
Series multi-flow (unbalanced)

1.22 Where the room has a nett surplus of mechanical extract air, a transfer grille should be located adjacent to the door through which the air flows inwards and the mechanical extract flow rate to the room should be chosen to give protection when this door is open.

1.23 The grille must be sized for the protection requirement of the opposing door when open. When the room on the high pressure side is depressurised there is a possibility of back-flow through gaps around the door, but this problem may be ignored.

Series multi-flow (balanced)

1.24 In these rooms a transfer device is required adjacent to each doorway to provide a flow path for the air required to protect the opposing door when opened.



Series multi-flow (balanced)

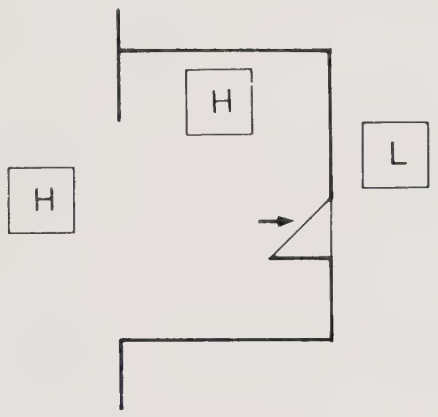
1.25 These transfer devices will normally be pressure stabilisers although transfer grilles may be used where a large amount of excess air is to be exhausted from the operating room when all doors are closed, for example, anaesthetic rooms.

1.26 The calculation procedure is to assume that pressure stabilisers are used and then if there is sufficient excess air, change to transfer grilles as described in paragraphs 1.43 to 1.44.

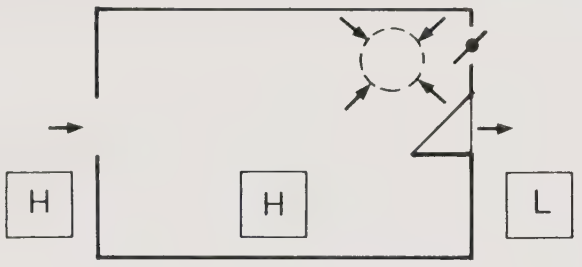
Bay

1.27

a. Open bay – a bay of the open type (for example, scrub-up) is considered to be part of the operating room and provided air movement is satisfactory no specific extract is required.



Bay (open)



Bay (semi-open)
Note: The pressure stabiliser may be replaced by mechanical extract.

b. Semi-open bay – in a bay of the semi-open type, protection of one area from the other is possible (for example, scrub-up).

   As stated in paragraph 6.2, the need for protection between operating room and scrub-room is not very great. Better use of air can therefore be achieved in this case by installing a pressure stabiliser between the scrub-room and clean corridor. This will allow a flow of air through the scrub-room at all times, except when a door is opened elsewhere in the suite. The pressure stabiliser will then close and the air will be diverted to the other door. When it is considered necessary to protect the scrub-room at all times, either a transfer grille to the corridor or mechanical extract in the scrub-room, should be provided.

Operating room

1.28 Once the peripheral rooms have been considered, the operating room requirements may then be decided and the supply flow-rate required for air movement control calculated. This flow-rate should be such that with any one door open the correct air movement directions are maintained. There will be one door in the suite which will require the largest supply flow rate to the operating room for protection when open. This is called the "key door" and is discussed separately in paragraph 1.32 below. Use of this concept avoids repetitive calculations for each door in turn. Having established the required supply flow-rate, a relief route must be provided to the clean corridor for any excess air when the doors are closed. This could be via transfer grilles or pressure stabilisers through a series flow room or via pressure stabilisers to the clean corridor directly.

Corridors

1.29 All the surplus air from the suite except that lost through structure leakage and any passing to the outer corridor will arrive in the patient/staff corridor. Should this air be insufficient to achieve the required air change rate (see Table 6.1), then some additional air supply should be provided. (The air balance should take account of structural leakage.)

Door opening

1.30 Whereas the resulting pressures are dependent upon the ductwork layout, the room relationships and the characteristics of the fan, the generalisations shown in Table 6.2 can be used to estimate the change in room pressure when a door is opened.

1.31 The "key door" will be the open double door which leaves the operating room at the highest pressure, and/or requires the largest air-flow. This will normally be the door to the anaesthetic room, but other doors should be checked using the procedure in Worksheet WS3.

Transfer grilles

1.32 These may be used to limit the pressure differences across the closed door of a single flow room or, in some instances, for protection of a series-flow or parallel-series flow room. They allow air-flow in both directions and may not be suitable for all applications.

1.33 The free area of a grille is calculated from:

$$A = \frac{Q}{0.84\sqrt{\Delta P}}$$

where: A is free area (m^2)
Q is flow rate (m^3/s)
ΔP is pressure difference (Pa)

The flow through a grille at a different pressure may be found from:

$$Q_2 = Q_1\sqrt{\frac{\Delta P_2}{\Delta P_1}}$$

where: Q_1 and ΔP_1 are original flow and differential pressure
Q_2 and ΔP_2 are new flow and differential pressure.

The transfer grille may be replaced by carefully proportioned door undercuts of the equivalent free area.

1.34 The function of the transfer grille is to provide a means of air-flow control by which the volume and pressure loss can be established. Any method which achieves this, for example carefully prepared door undercuts or a simple framed opening is satisfactory. If a grille is used, it should have an easily removable core to facilitate cleaning.

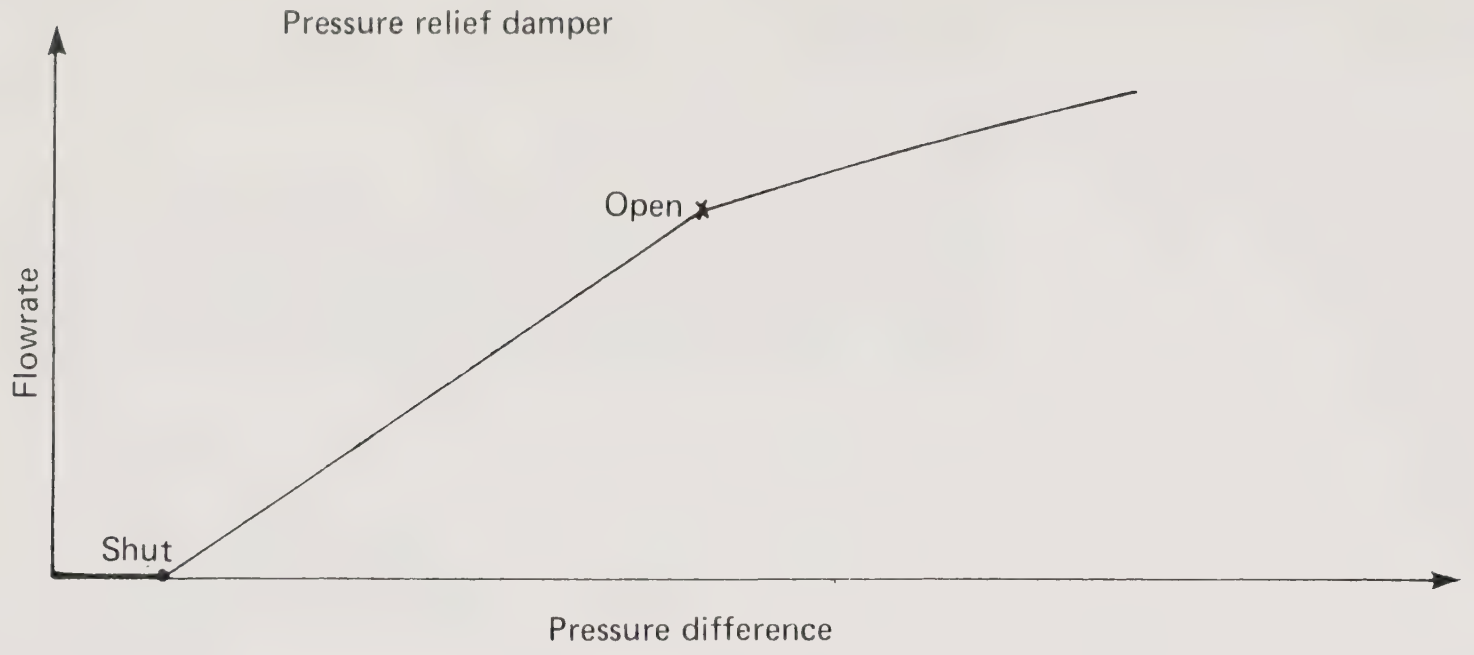
Key to figures (see paragraphs 1.13 to 1.27)

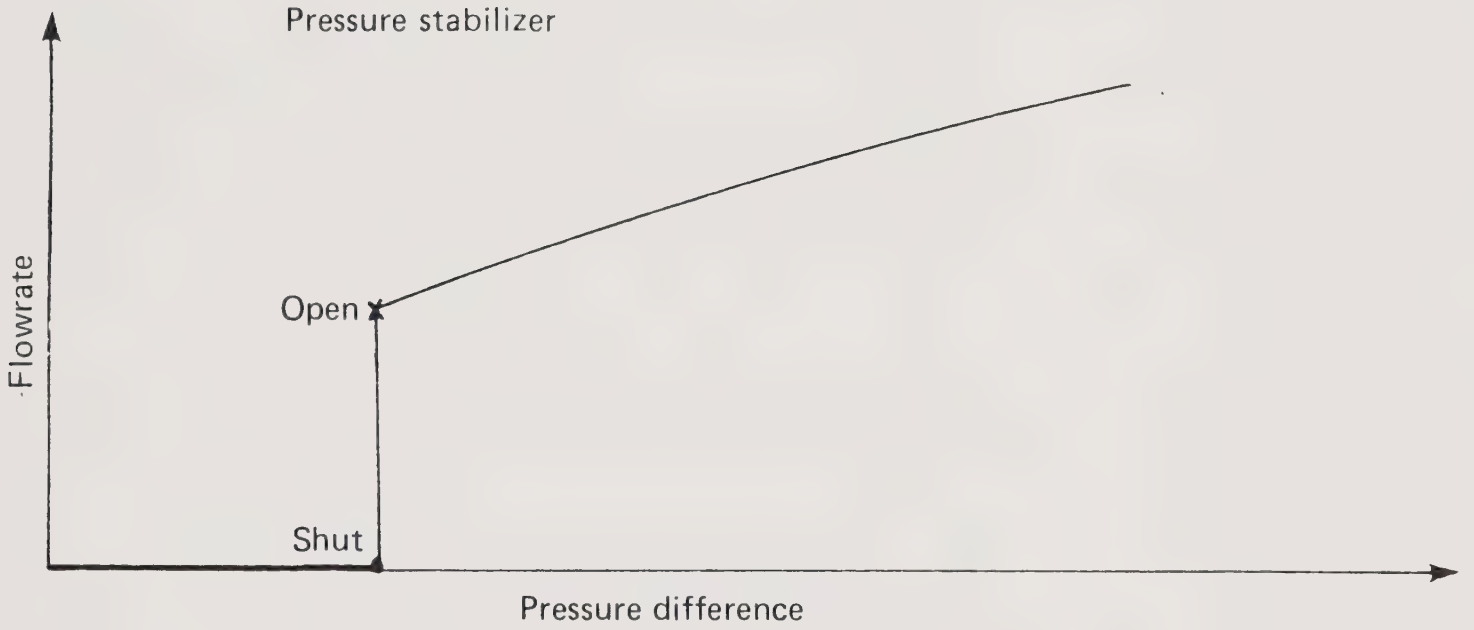
H M L High, medium or low pressure

All other symbols as per key to Figure 6.1

Pressure relief dampers

1.35 Pressure relief dampers have an approximately linear flow/differential pressure characteristic, but do not have the steep characteristic of the pressure stabiliser (see Figure B1). They are therefore not suitable for accurately controlling pressure to a pre-set level, but may be used to control air volume, allowing excess air to vent when not required to protect an open doorway. The damper may then be sized to give the desired room pressure at the known flow-rate.





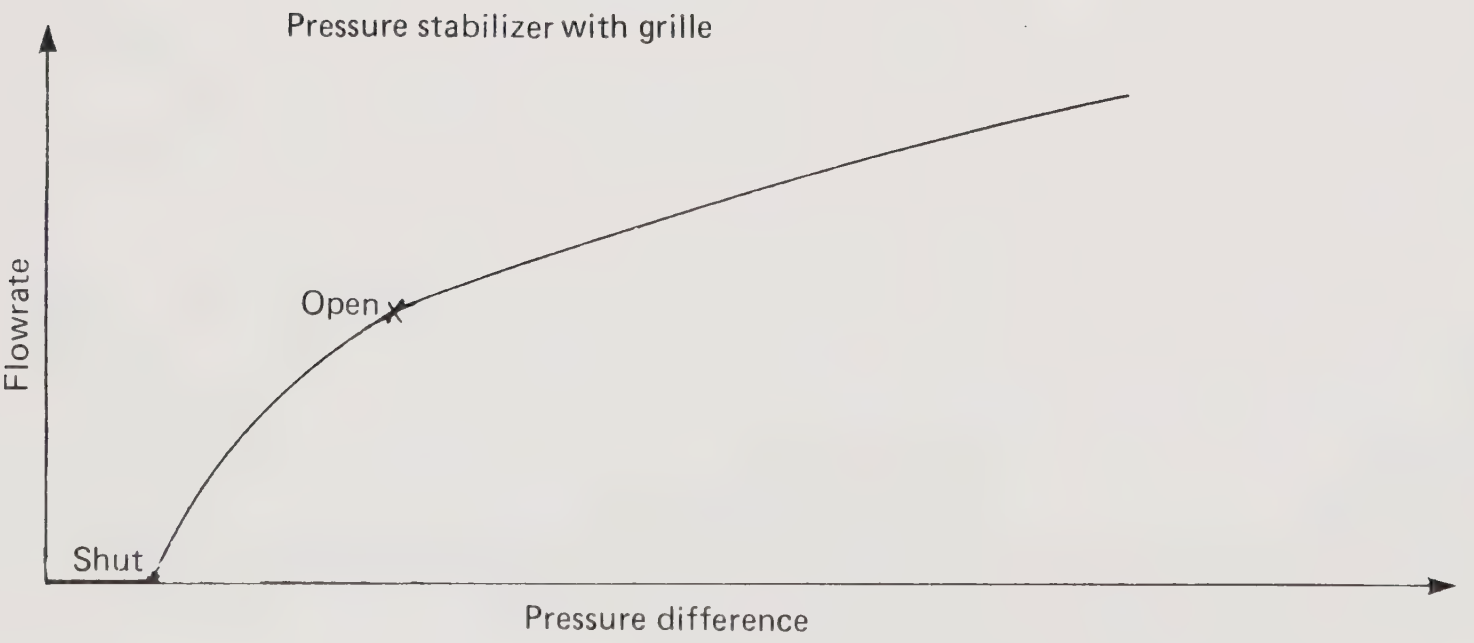


Figure B1 Typical flowrate/pressure characteristics

Pressure stabilisers

1.36 Pressure stabilisers (Figure B1) have a steep flow-rate differential pressure characteristic. They, therefore, hold the pressure constant over a wide range of flow-rates. They are useful where requirements exist for accurate room pressure control or rapid shut-off on pressure fall.

1.37 Because the installation of a grille in association with a stabiliser will seriously alter the operating characteristics, it is recommended that a location be chosen to avoid the need for visual screening for example, at high level. The location should be chosen to minimise the likelihood of damage.

1.38 The stabilisers used should be virtually silent in operation, adjustable on site, maintenance free, and of a type which cannot be wrongly inserted. They should not be used in external walls or where the pressure difference is less than 1OPa. The required size of a pressure stabiliser is dependent on the design pressure difference across it and flow-rate through it. The manufacturer should provide data relating pressure difference to mean velocity (or flow-rate per unit area). From this the required area can be calculated and then rounded-up to the nearest size manufactured or nearest combination of smaller sizes.

1.39 It is sometimes possible to arrange for a pressure stabiliser to perform two tasks. In an anaesthetic room for example, the two pressure stabilisers may be made to pass the open door protection air, and also control the operating and anaesthetic room pressures with the door closed. To achieve this the stabilisers are sized for the flow-rate required with one of the doors open, but the pressure setting is adjusted to be the value required with the doors closed. This is shown in Figure B2.

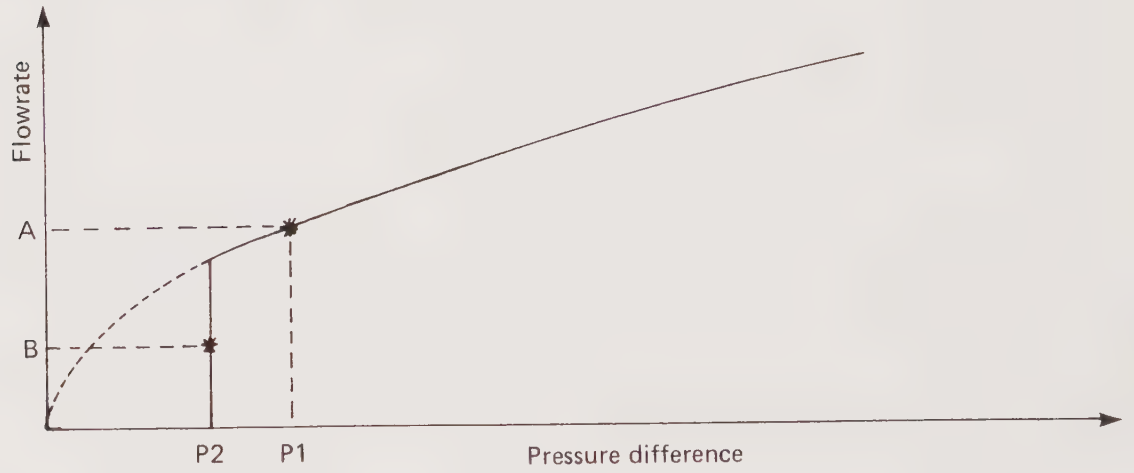


Figure B2 Pressure stabilisers performing two tasks

Note: The size of the unit is chosen to give (as nearly as possible) the door protection flow A against the pressure difference P1. The stabiliser will be fully open and acting as an orifice.

The pressure setting of the stabiliser is adjusted to P2 to control the closed door room pressures (P2) by passing flow B.

Door leakage flows

1.40 For an air movement control scheme to work satisfactorily it is essential that the estimates of door gap leakage made at the design stage are closely related to those which are achieved in practice. The calculation of gap-flows is complicated by the fact that such flows generally fall into the transition region between laminar and turbulent flow and hence do not follow the normal flow equations. Leakage flows have been calculated for doors installed to the specification in the CDB (Component Data Base). The gaps assumed are 4 mm along the bottom, 3 mm at the top and sides and 2 mm between double leaves. Doors should not have wider gaps than these. Tighter gaps would result in

lower flow-rate requirements and hence lower fan power, but care should be taken to ensure that all doors in the suite have similar gap dimensions.

Room temperature estimation

1.41 The air flow-rate required to prevent backflow through an open door is dependent on the temperature difference across the door. The design figures shown in Table 6.2 are based upon the temperature differences which will normally occur in practice, assuming heat gains and losses in accordance with Table 6.4.

1.42 At step 11 of the air-flow design process the temperature differences across the doors of all rooms classed as "sterile" are calculated. Worksheet WS6 is recommended for the calculations, using the following criteria:

a. assume that the operating room is being controlled at 20°C and calculate the incoming air supply temperature as shown on Worksheet WS6;

b. the calculation should be repeated for both summer and winter conditions, with an operation in progress;

c. assume all doors are closed;

d. use the room supply flow-rates from WS1;

e. use the inward air-flows through air transfer devices and closed door leakages from WS2a to WS2e;

f. the formulae used in Worksheet WS6 is as follows:

$$T = \frac{(Q_1t_1 + Q_1t_2 + \ldots + Q_nt_n) + 0.828H}{(Q_1 + Q_2 + \ldots Q_n)}$$

where: Q_1 is flow-rate from Source 1 (m^3/s)

t_1 is the temperature of Source 1 (°C)

H is room heat gain kW.

If the evaluated temperature differences between rooms do not exceed 2°C the solution is satisfactory, otherwise proceed as follows:

(i) check the assumption on which the heat gains are based;

(ii) take steps to reduce the heat gains;

(iii) if the door is to a corridor, the flow through the open door will be larger than the value given in Table 6.2. Calculate on WS3 assuming it is the "key door" with door-flow unknown, and the supply as known;

(iv) If the door leads to a room with mechanical supply, install a trimmer heater in the supply to the room controlled by either a differential thermostat or a thermostat slaved to the operating room thermostat to ensure that ΔT is minimised;

(v) if the door leads to a room with no mechanical supply, increase the door protection flow as follows:

$$Q_{new} = Q_{old} \times \frac{\Delta T + 1}{2}$$

These options should be considered in this order and (i), (ii) and (iii) should be investigated thoroughly before procedding to (iv) or (v). The mechanical supply should be increased in exceptional circumstances only and in no case should the supply flow-rate to the operating room exceed 1.0 m^3/s.

Relief of excess air from operating room when all doors are closed

1.43 As the mechanical supply to the operating room is sized to provide an appropriate flow outward through any door which is opened, it follows that when all doors are closed there will be more air supplied to the operating room than can exit from it via leaks etc. This "excess" air can be relieved by either of the two methods following.

By transfer devices via the anaesthetic room

1.44 For door protection the transfer devices in the anaesthetic room are typically designed to pass 0.47 m^3/sec at a differential pressure of 14Pa. When the doors are closed the differential pressure will change to 11Pa and the volume of air passed by the transfer devices will be modified as shown in the following formula:

$$Q = Q1 \left(\frac{\Delta P_1}{\Delta P_2}\right)^{1/2}$$

$$= 0.47 \times \left(\frac{11}{14}\right)^{1/2}$$

$$= 0.42 \ m^3/sec.$$

Q = "excess" air to be vented with doors closed.

Q_1 = air flow required for door protection through transfer device.

ΔP_1 = nominal differential pressure with door to operating cess room closed and door to corridor closed.

ΔP_2 = nominal differential pressure between, either the anaesthetic room and corridor when the operating room door is open or the anaesthetic room and operating room when the corridor door is open. This differential pressure is used when selecting *size* of both devices.

a. If the "excess" air is less than 0.42 m^3/sec, a pressure stabiliser is required to ensure that the correct protection air-flow is available to pass through the door.

b. If the "excess" air is greater than 0.42 m^3/sec, a transfer grille will be acceptable because at all times the air-flow will exceed the flow required for door protection.

By pressure stabilisers to the corridor.

1.45 If it is undesirable to pass operating room air through the anaesthetic room, it may be passed directly to a corridor via a separate pressure stabiliser.

1.46 If there is sufficient "excess" air, the transfer grille solution at 1(b) above should be adopted, as it provides the simplest solution and once set up, will require no further maintenance. With less "excess" air it is recommended that the air be passed through the anaesthetic room via the pressure stabilisers as at 1(a) above, thus keeping the number of pressure stabilisers to a minimum. Both these solutions increase the air change rate in the anaesthetic room.

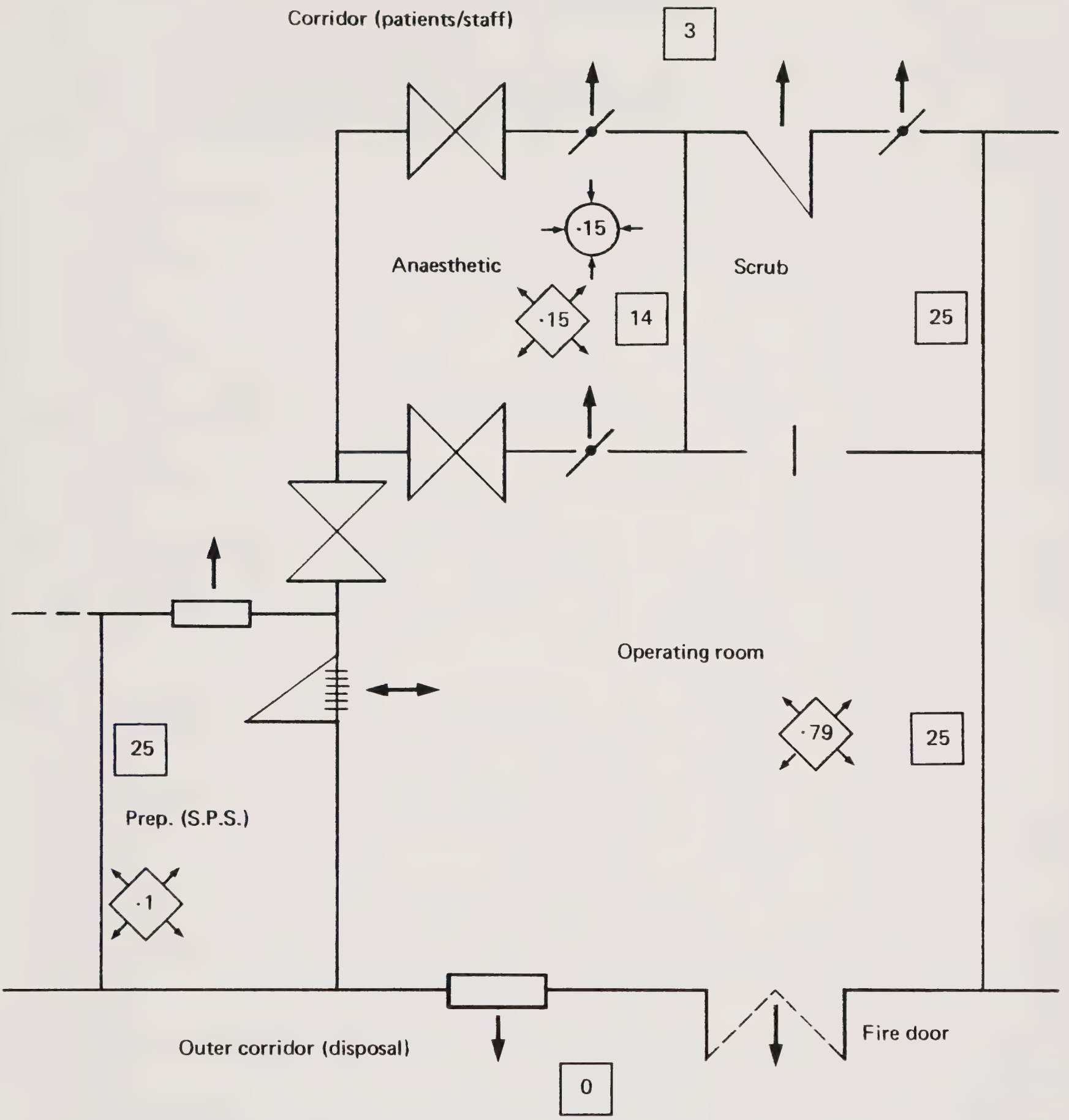


Figure C1 Plan of operating suite – Nucleus plan – Two corridor with sterile pack store and disposal hatch

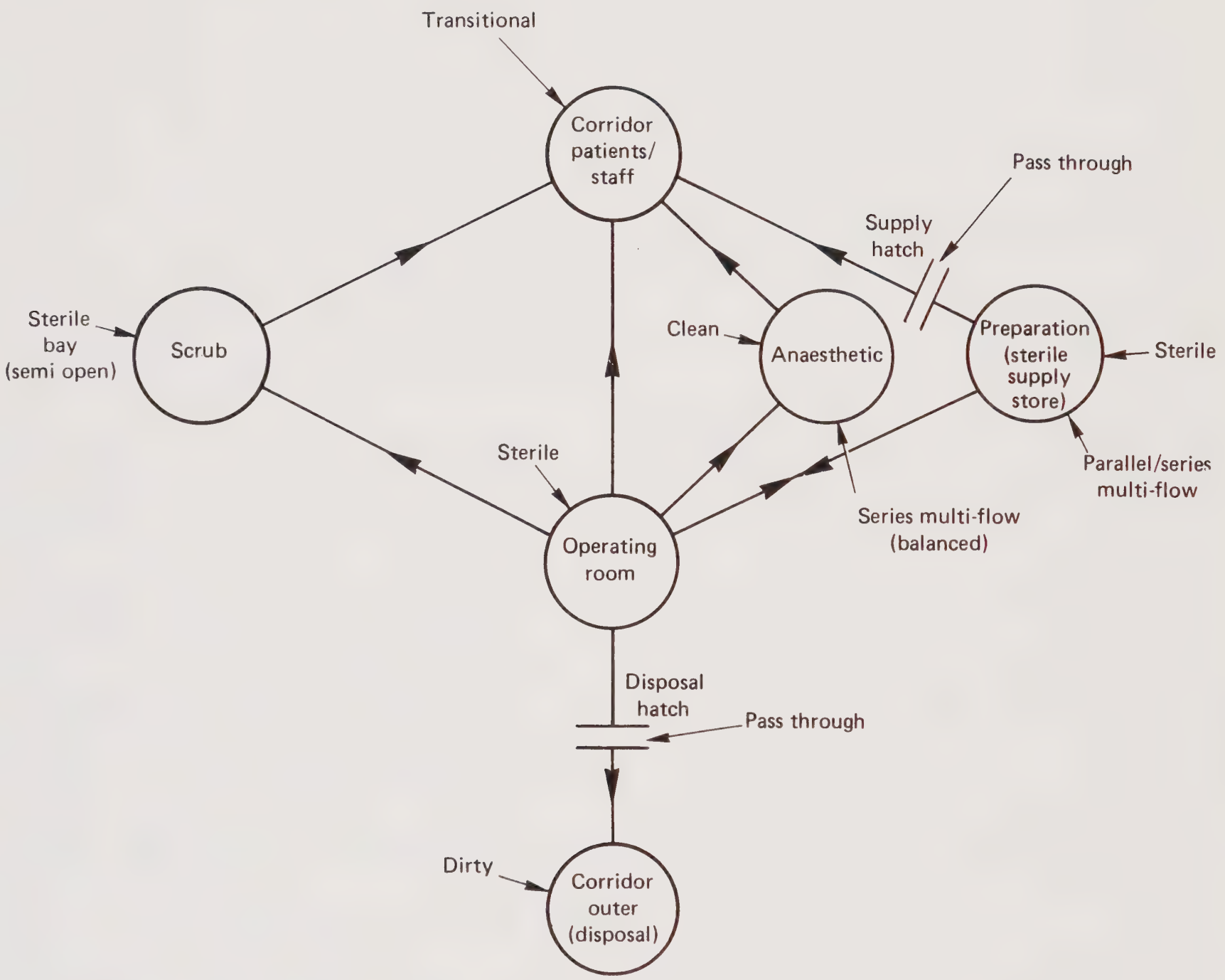


Figure C2 Air flow network

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